Ministry
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Water Resources
Report 11 b

Northern Ontario
Water Resources Studies

Ground - Water Resources

Ministry of the environment

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WATER RESOURCES
REPORT 11b

Northern Ontario Water Resources Studies

Ground - Water Resources

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MINISTRY OF THE ENVIRONMENT
Water Resources Branch

Toronto Ontario

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PREFACE

In October 1965, the Prime Minister of Canada and the Premier of Ontario agreed to undertake a series of co-ordinated studies of northern Ontario's water resources and related economic development. Subsequently, a co-ordinating committee representing the two levels of government was established and a statement of objectives for the studies was prepared as follows:

> "With respect to water draining into James Bay and Hudson Bay in Ontario, to assess the quantity and quality of water resources for all purposes; to determine present and future requirements for such waters, to assess alternative possibilities for the utilization of such waters locally or elsewhere through diversions."

This report deals with the interpretation of ground-water data obtained by the Ontario Ministry of the Environment and by other agencies during the period from 1966 to 1972. The availability and the chemical quality of ground-water resources in five major river basins (Moose, Albany, Attawapiskat, Winisk, and Severn) in northern Ontario are evaluated. Other reports by the Ministry of the Environment in the northern Ontario water resources study series deal with the quality and quantity of surface water and will be published separately.

This report should be of interest to those who are concerned with the regional development of the ground-water resources and to those who are undertaking local studies in northern Ontario.

G. H. Mills, Director
Water Resources Branch

Toronto, 1978

ENGLISH-METRIC (SI) FACTORS

to convert	to	multiply by
inches (in)	centimetres (cm)	2.540
feet (ft)	metres (m)	0.305
miles (mi)	kilometres (km)	1.609
cubic feet per second (cfs)	litres per second (l/s)	28.316
gallons (g)	litres (l)	4.546
gallons per minute (gpm)	litres per second (l/s)	7.577×10^{-2}
gallons per minute per foot (gpm/ft)	litres per second per metre (l/s/m)	2.309×10^{-2}
gallons per day per foot (gpd/ft)	square metres per day (m^2/d)	1.491×10^{-2}
gallons per day per square foot (gpd/ft^2)	metres per day (m/d)	4.892×10^{-2}
million gallons per day (mgd)	litres per second (l/s)	52.616
million gallons per day per square mile (mgd/mi^2)	litres per second per square kilometre (l/s/km^2)	20.323
pounds per square inch (psi)	kilo-Pascal (kPa)	6.894

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(in pocket)

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ABSTRACT

A study of the occurrence, distribution, quantity and quality of ground water in northern Ontario was undertaken in five large watersheds that drain into Hudson Bay and James Bay. This study was part of a comprehensive water-resources study conducted by the Ministry of the Environment during the period from 1966 to 1972. Ground-water related field work in the five basins (Moose, Albany, Attawapiskat, Winisk and Severn) included geologic mapping, ground-water sampling, seismic surveying, drilling of 21 test holes, and establishing an observation-well network.

The report presents brief descriptions of geography and geology but deals in detail with the distributions, subsurface characteristics and hydraulic properties of aquifers. Water quality, water uses and the potential for future development are dealt with in lesser detail.

The study area is generally divisible into two hydrogeologically significant zones: a Precambrian rock zone covering the southern part of the study area, and a Paleozoic rock zone located in the northern part of the study area.

In general, overburden deposits are the principal aquifers in the area of Precambrian rocks; however, there are large areas where fractured crystalline rocks are often the only water-yielding formations. The most productive overburden aquifers consist of sands and gravels associated with outwash deposits and eskers. The mean transmissibility of wells penetrating these aquifers is about 5000 gpd/ft and individual wells average about 200 gpm. Of secondary importance in the Precambrian rock area are sands associated with lacustrine deposits and sand tills which are generally widely distributed but considerably less productive; the mean transmissibility of aquifers consisting of these materials is low, about 500 gpd/ft, but individual wells may yield up to 25 gpm. Ground-water samples from the overburden aquifers indicate generally potable water.

Many wells in the Precambrian rock area obtain water from fractured crystalline rocks because overburden is either thin, absent or poorly permeable. The mean transmissibility of these rocks is generally very low, about 200 gpd/ft, and yields of individual wells are barely enough for domestic uses. Ground-water samples indicate generally potable water.

In the area of Paleozoic rocks, bedrock aquifers are the principal sources of water because overburden consists mainly of poorly permeable tills, clays and silts. The most productive aquifers are located in fractured limestone/dolomite rocks. The mean transmissibility of wells in these rocks is about 5000 gpd/ft and individual wells may yield up to 200 gpm. The quality of ground water varies from fresh in areas near the Precambrian-Paleozoic contact to brackish in coastal areas.

The total recharge to ground water in the five river basins is estimated to be 19 billion gpd. This recharge is equivalent to an annual infiltration of about 2.7 inches over the five basins, or about 10% of the annual precipitation of 26 inches.

Ground-water withdrawals in 1972 are estimated to be 7.4 million gpd, or less than 0.1 percent of the estimated annual recharge to ground water. Domestic and municipal uses account for 81% of the total withdrawals, the rest being used by industrial, commercial, irrigation and public facilities.

Figure 1. Location and extent of northern Ontario water - resources studies area.

INTRODUCTION

THE NORTHERN ONTARIO WATER RESOURCES STUDIES

During the period from 1965 to 1972, the governments of Canada and Ontario undertook a series of co-ordinated studies of northern Ontario's water resources and related economic development. The work was undertaken in five large river basins that drain into Hudson Bay and James Bay. From northwest to southeast, these are: the Severn, the Winisk, the Attawapiskat, the Albany, and the Moose River basins.

The Government of Ontario delegated its part in the hydrologic and engineering aspects of the studies to the Ontario Water Resources Commission (OWRC), which is now part of the Ministry of the Environment (MOE). The OWRC assigned the former Hydrologic Data and the Surveys and Projects branches of the Division of Water Resources to pursue these studies. Many of the functional responsibilities of the former OWRC-Division of Water Resources now rests with the MOE-Water Resources Branch.

Data and information on streamflows, ground-water levels, snowfall, water chemistry, water biology, and hydrogeology, all of which were collected by the OWRC and the MOE, have been published in Water Resources bulletins 1-1 through 1-5. This report on ground water is one of three reports scheduled to be published by the MOE. Other reports in the northern Ontario water resources study series deal with the quality and quantity of surface water and will be published separately.

SCOPE OF INVESTIGATION

Hydrogeologic work was started in 1966 and included reconnaisance surveys, mapping of surface geology in the five major drainage basins, drilling of 21 test holes, hydraulic tests on many water wells, a seismic survey in the Nakina area, the establishment of an observation-well network, and the collection of more than two hundred water samples from wells and springs.

This report describes the bedrock and surficial geology, the delineation of surficial and bedrock aquifers, an evaluation of their hydraulic properties and the determination of changes in storage of the aquifer systems from water-level fluctuations. The chemical suitability of ground water for domestic and other uses, and the present development and the potential for future development in various parts of the study area are also discussed.

LOCATION AND EXTENT OF THE STUDY AREA

The total northern watershed of Ontario (Figure 1) comprises an area of approximately 212,000 square miles. It extends from Hudson Bay and James Bay to the height of land that divides waters flowing north from those flowing south.

This report focuses on five major drainage basins of which the Albany River basin (51,700 mi^2) is the largest, followed by the Moose River (41,900 mi^2), the Severn River (37,600 mi^2), the Winisk River (26,200 mi^2), and the Attawapiskat River (19,300 mi^2) basins . Total area of the five basins is 176,700 square miles or 83% of the total area of the northern watershed. While investigations have not been carried out in the Ekwan and other small river basins, results from the five major river basins may be extrapolated to cover the remaining 17% of the area.

PREVIOUS INVESTIGATIONS

Previous investigations in northern Ontario have dealt primarily with identifying and mapping geologic units of both surficial and bedrock formations. Early geologic investigations are those of Bell (1887), Borron (1891), Bell (1904), Wilson (1906), Keele (1920), and McLearn (1927). Maps and reports have been published by the Geological Survey of Canada (Hughes (1956), Prest (1963), McDonald (1968), Sanford et al (1968), Craig 1969)) and the Ontario Department of Mines (Satterly (1953), Zoltai (1965), Boissoneau (1966, 1968), Bennett et al (1967), Thurston et al (1970)). More recent works of the Canada Department of the Environment (1972) and the Geological Survey of Canada (Douglas (1970), Skinner (1973)) have added further knowledge to the geology and subsurface stratigraphy within the study area.

On the subject of ground water are reports of Brown (1970) who briefly discussed hydrogeology of the Canadian Shield and of Parsons (1970) who studied ground-water movement in a glacial complex in the Cochrane area.

Streamflow data used in this report are published by the Water Survey of Canada. Meteorological data are published by the Atmospheric Environment Service.

Many local investigations into the feasibility of municipal water supplies have been conducted by the Ontario Ministry of the Environment. Reports of these investigations are on file at the Ministry's office in Toronto.

Records of geologic exploratory borings and of wells for water, oil and gas, and results of seismic investigations in the study area are the basis for subsurface information used in this report. Most of the water-well records are on file with the Ontario Ministry of the Environment. Records of some test holes were furnished by the Canada Department of Environment.

ACKNOWLEDGEMENTS

This report is the culmination of work by many people of this Ministry. Investigations were carried out under the general supervision of Messrs. K. E. Symons, Director, and D. N. Jeffs, Assistant Director of the Division of Water Resources of the former Ontario Water Resources Commission. Field geologic mapping, hydrogeologic testing and data collection, and water sampling were performed by personnel of the former Surveys and Projects Branch and the Hydrologic Data Branch. Geotechnical services were provided by personnel of the former River Basin Research Branch.

The success of this investigation was due to the co-operation and support received from various agencies outside the OWRC. The Canada Department of Environment permitted the use of their test holes as observation wells. Their personnel helped in pumping tests and collected water samples from test holes. The Ontario Ministry of Natural Resources and their regional officers supplied equipment needed to install observation wells in the Nakina, Pickle Lake and Moosonee areas.

The cooperation of the residents within the study area during the water sampling program is gratefully acknowledged.

Mr. T. J. Yakutchik and Mr. R. Pikula offered helpful suggestions during the course of the field survey. Messrs R. C. Hore and U. Sibul provided constructive comments during editing of the report. Finally, thanks to Miss. J. Lobsinger for her work in typing this manuscript.

GEOGRAPHY

PHYSIOGRAPHY

The regional physiographic map (Map 1) outlines the physical features of the land surface. It reflects the surficial and bedrock geology of the area and the past effects of water, ice and wind on the surface.

Northern Ontario is composed of two major physiographic regions: the Precambrian Shield Region in the south and the Hudson Bay Lowland Region in the north. The boundary between the two regions is approximately the 500-foot ground surface contour.

Precambrian Shield Region

The Precambrian Shield Region (hereafter referred to as the Shield Region) is underlain by rocks of the Precambrian Era. Land surface elevation is approximately 1500 feet at the southern boundary and drops to 500 feet at the lower boundary in the north, giving a total relief of 1000 feet.

The Shield Region is subdivided into three physiographic subregions. From south to north, they are: the Upland Area, the Lacustrine Plain, and the Till Plain.

Upland Area.... This is the most southern subregion and is an area of rolling upland which is mantled by very thin sand till over highly resistant crystalline rocks. Most of the land surface lies between an elevation of 1200 and 1500 feet, but local ridges in the south may rise up to 1800 feet above sea level.

End and interlobate moraine ridges are characteristic topographic features in the Upland Area. The Kaiashk Interlobate Moraine (Zoltai, 1965) in the Albany basin east of the English River rises to 200 feet above its surroundings. Relief of the Agutua Moraine (Prest, 1963), which extends from just east of Sandy Lake in the Severn basin to about the Ogoki Reservoir in the Albany basin, is commonly more than 200 feet and reaches 550 feet at longitude 89°05'. Ridges of the Nakina (Zoltai, 1965) and the Chapleau moraines (Boissonneau, 1968) near these communities are commonly more than 100 feet high.

Other topographic features in the Upland Area are northwest-trending esker ridges which rise 50 to 100 feet above the surrounding country.

Lacustrine Plain.... The Lacustrine Plain subregion is located north of the Upland Area and stretches from the Ontario-Quebec border westward to the Ontario-Manitoba border. Land surface elevation is 1200 feet at the southern boundary and drops to 800 feet at the northwestern boundary. The maximum relief is approximately 400 feet.

Morainic ridges and eskers are the main topographic features in the subregion. Several systems of moraines bound the plain on the western side. The Arnott Lake Moraine (Boissonneau, 1966) north of Hornepayne rises 100 feet above the surrounding area. Eskers trend east to northeast with local relief up to 150 feet.

Till Plain.... The Till Plain subregion lies north of the Lacustrine Plain. The topography is characterized by a plain of low relief, sloping at approximately 6 feet per mile towards the Hudson Bay Lowlands from elevations of 800 to 1000 feet at the southern boundary. Total relief is 300 to 500 feet.

The most conspicuous topographic features in this subregion are the large kame moraines: the Pinard Moraine (Boissonneau, 1966) north of Kapuskasing, which rises 175 feet above its surroundings and two segments of the Arnott Lake Moraine which rise to 100 feet in the southeastern part of the area. Other topographic features are eskers, drumlins and flutings. Their reliefs are generally less than 50 feet.

Hudson Bay Lowland Region

The Hudson Bay Lowland Region (hereafter referred to as the Lowland or Lowland Region) comprises about one-third of the total surface area of northern Ontario. It is a vast, swampy, marshy plain with clay and till mantling the Paleozoic strata. Ground elevations of 500 feet are reached at the northeastern boundary on an escarpment which overlooks the plain. The lower part of the Lowland is a unique string of bogland consisting of low ridges and wet hollows. The slope of the bogland is approximately 3 feet per mile towards Hudson Bay and James Bay.

The most conspicuous topographic features in the Lowland Region are the Sutton Ridges which rise to about 500 feet above their surroundings. These ridges are located south of Hudson Bay and east of North Washagami Lake and are composed of crystalline rocks of Precambrian age. The major topographic features along the coastal areas consist of strand lines which rise approximately 10 to 30 feet above their surroundings. They are often several miles long but seldom exceed a few hundred feet in width.

DRAINAGE

Eighty-three percent of the northern Ontario study area is drained by five major rivers: the Moose River, the Albany River, and the Attawapiskat River, all of which flow into James Bay, and the Winisk River and the Severn River which flow into Hudson Bay. The headwater areas of these rivers are in the Precambrian Shield Region.

The Moose River has three major tributaries: the Abitibi, Mattagami and Missinaibi branches. Their total drainage area is 41,900 square miles. These streams descend 1600 feet from their source in the south, a distance of approximately 300 miles to James Bay. Gradients of the branches steepen markedly near the faulted Precambrian-Paleozoic contact. Strong rapids occur on the Abitibi, Mattagami and Missinaibi branches in the contact area.

The Albany River, together with its four major branches, the Kenogami, Little Current, Ogoki and Cat rivers, drains an area of 51,700 square miles. The upper part of the Albany basin is characterized by numerous lakes connected by narrow streams that contain many falls. The drainage pattern is controlled largely by fractures and joints in the Precambrian rocks. The lower part of the Albany River system follows the structure of the Paleozoic rocks. Rivers in this part have fairly uniform gradients with no prominent rapids.

The Attawapiskat River, together with its tributaries of the Pineimuta and the Otoskwin branches, drains an area of about 19,300 square miles. In the upper parts of the basin, the drainage pattern is controlled mainly by glacial overburden features and the streams and lakes flow northwesterly. In the lower part, the basin is poorly drained. Cliffs of limestone more than 40 feet high characterize the lower reaches of the Attawapiskat River.

The Winisk River drains an area of about 26,200 square miles. Both the Asheweig and the Pipestone branches are characterized by numerous parallel lakes and the drainage pattern is controlled mainly by glacial features. The lower part of the Winisk River has a broad zig-zag course which is probably controlled by Paleozoic bedrock.

The Severn River drains an area of 37,600 square miles. The upper part of the river is characterized by chains of large lakes connected by short channels with numerous rapids. Two large tributaries, the Sachigo and Fawn branches, enter the Severn in the lower reach where stream gradients flatten and drainage becomes poor. Snowmelt and rainfall in the early summer turn the area into a large, shallow lake.

CLIMATE

Temperature, precipitation and evapotranspiration are the important climatic factors that relate directly to the availability, storage and movement of ground water.

The climate of northern Ontario is sub-arctic, characterized by a short, cold summer with one to three months of temperatures above freezing. Mean daily temperatures for June and July range from 12°C in the extreme north along the shore of Hudson Bay, to 16°C in the vicinity of the major divide. Generally, winter temperatures range from -15°C in the southeast to -26°C in the northwest.

Half of the annual precipitation falls in the late summer and early fall. Annual precipitation decreases from 33 inches in the southeast to 18 inches in the northwest. Average snowfall ranges from 60 to 100 inches.

Evapotranspiration (ET) varies from more than 20 inches in the south to less than 16 inches in the far north. Precipitation usually exceeds evapotranspiration from September to April, but is approximately equal to the ET in May (Chapman et al, 1968). Rest of the year the evaportranspiration exceeds precipitation.

POPULATION AND ECONOMY

The study area contains the District of Cochrane and portions of the districts of Kenora, Thunder Bay, Sudbury and Timiskaming. Principal communities occur along the major transportation routes in the south. The two largest communities are Timmins and Kapuskasing, each with a population of more than 10,000. The Hudson Bay Lowlands are practically unpopulated except for a few villages scattered inland and along the bay shore.

Railways remain the major transportation routes in the area. Highways are few and access to settlements in the Lowland Region depends largely on airways.

Mining, pulp and paper are important industries in the southern region. Agriculture is carried out only around the main settlements in Cochrane, Kapuskasing and Timmins.

GEOLOGY

BEDROCK GEOLOGY

Stratigraphy

Rocks in northern Ontario may be divided into two major groups. The oldest group consists of igneous and metamorphic rocks of early to late Precambrian age (Map 2). They outcrop or underlie the overburden in the southern part of the study area to form the Canadian Shield. In the northern part they are overlain by flat-lying, undeformed sedimentary rocks of Paleozoic age. A small patch of Cretaceous rocks occurs in the east just north of the Precambrian-Paleozoic contact.

The Canadian Shield consists, for the most part, of large areas of granitic and gneissic rocks of Precambrian age. Within the areas of these rocks, there are numerous widely dispersed inliers of highly deformed and metamorphosed sedimentary and volcanic rocks. The volcanics are mostly basic with some acidic portions. The sediments are mainly interbeds of greywacke and shale with conglomerates near the base above the volcanics. Maximum thickness of the volcanic-sedimentary sequence is 55,000 feet (Douglas, 1970).

In addition to the inliers and associated intrusions in the Shield Region, there are scattered areas of sedimentary and intrusive rocks of middle to late Precambrian age. The sedimentary rocks lie uncomformably over early Precambrian rocks and are generally non-metamorphosed. The intrusions are plugs of an alkaline complex and igneous rocks that cut the early granite gneisses and volcanics.

The Paleozoic rocks are, for the most part, of marine origin. They are represented by 16 formations, ranging in age from Ordovician to Devonian. Maximum combined thickness of the formations is approximately 1800 feet. Approximately 56 percent of the sedimentary sequence is carbonate rocks (limestone, dolomite, sandy limestone, dolomitic sandstone, etc.), clastic sediments (siltstone and sandstone) 42 percent and evaporites (mainly gypsum) 2 percent (Whitmore et al, 1968).

Cretaceous rocks occur in the extreme southeastern part of the Lowland Region and consist of fire clay, micaceous quartz sand and lignite. Maximum thickness of the strata is about 170 feet.

Structure and Topography

Early Precambrian metamorphic rocks are generally strongly folded and are characterized by easterly trending structures most pronounced in the western part of the map area. Curved structures are characteristic in the intervening areas where batholithic intrusions (igneous rocks) predominate. In the eastern part, these structures are cut by northeasterly striking faults. Locally the folded rocks are overlain by unfolded to gently folded late Precambrian sediments.

Paleozoic strata in northern Ontario, although relatively flat-lying, have been warped into two large sedimentary basins, the Moose River Basin and the Hudson Basin, separated by the northeasterly trending Cape Henrietta Maria Arch (Sanford et al, 1968). Sedimentary strata in the Moose River Basin dip gently southeasterly and the bottom of the basin is approximately 1800 feet below ground surface. In the Hudson Basin to the northwest, the sedimentary strata dip gently north to northwest where the sediments are approximately 1500 feet thick on the mainland.

The bedrock surface is irregular and largely exposed in the southern part of the Shield Region. The surface is characterized by low relief with numerous depressions and linear fracture openings. Bedrock surface is relatively flat in the Lowland Region and is deeply trenched with valleys and channels. The valleys of large rivers are generally coincident with these bedrock valleys.

Elevation of the bedrock surface is more than 1500 feet at the southern boundary of the Shield Region and drops to approximately 100 feet below sea level at the shore of Hudson Bay. Regional slope of the bedrock surface is approximately 7 feet per mile in the Shield Region and about 3 feet per mile in the Lowland Region.

An escarpment in the eastern part of the Precambrian-Paleozoic contact is a prominent topographic feature. Elevation difference of the bedrock surface across the escarpment is approximately 200 feet.

OVERBURDEN GEOLOGY

The surficial geology of northern Ontario is shown in Map 3. The complex Pleistocene history is indicated by a wide variety of glacial deposits and landforms. By the end of the Wisconsinan, most of the land surface in northern Ontario was underlain by drift from a few feet to more than 600 feet thick. The thickest drift occurs where the glaciers filled old bedrock valleys or built moraines.

As the last glacier retreated from the study area, the Tyrell Sea invaded the northern regions and left a layer of marine sediments over the glacial deposits.

Ground Moraine Deposits

Sand till is the most widely distributed surficial deposit throughout the rolling Upland physiographic subregion. The till mantle is thin and discontinuous; exposures of bedrock are abundant. In the Lacustrine Plain subregion, sand till overlies bedrock in the valleys and is in turn overlain by lacustrine deposits. This basal till is moderately compact, stoney and composed of pebbles and cobbles in a silty sand matrix. Its thickness averages about 15 feet but attains a maximum of about 80 feet in deep bedrock valleys.

Clay till is the dominant surficial deposit throughout the rolling Till Plain physiographic subregion. Occasional pebbles are present; large stones and boulders are rare.

In the Lowland Region, clay tills which form the bulk of overburden deposits are overlain by marine sediments. The tills consist of three or more units separated by fluvial or lacustrine sediments. The lower unit is generally hard, compact, calcareous silt till. The middle unit is a compact, brown, calcareous sandy silt till. The upper unit is a brownish grey clay till that is less compact than the older tills. Limestone pebbles are abundant in all three till units.

End Moraine and Interlobate Moraine Deposits

End moraine deposits in northern Ontario vary widely in composition and thickness. Materials in the Agutua Moraine (Prest, 1963), which is the largest moraine system in the north, vary from boulderly and slightly clayey sand till to boulderly and clean, silty sand till. These deposits are commonly more than 200 feet thick and attain a maximum thickness of 550 feet at longitude 89°05'. The Pinard Moraine at the Fraserdale/Smoky-Falls area north of Kapuskasing is composed mainly of silt and sand. Maximum thickness is 175 feet. Small end moraines in the Nakina, Chapleau and Wunnumin Lake areas are composed of stoney and boulderly sand and gravel.

Interlobate moraine deposits also vary in composition and thickness. The Kaiashk Moraine at the southern tip of the Albany River basin is composed of stratified sand and gravel with a large number of boulders. Maximum thickness is 200 feet. The Arnott Lake Moraine north of Hornepayne is composed of slightly stoney, coarse to medium sand. Maximum thickness is approximately 100 feet.

Eskers, Esker-Kame Complexes

Eskers are numerous and widely dispersed in the south. They are generally elongated ridges flanked by broad outwash areas. In the Cochrane and Smooth Rock areas, eskers occur as low, broad ridges flanked by rows of kettle holes. Kames are present locally at the head of eskers or head of segments of esker systems.

Most common esker-kame complex materials are sands and gravels which may vary from well sorted and well-graded to those resembling gravel tills in the area. However, esker ridges composed of only silt and fine sand are also reported in the Badesdawa Lake area (Prest, 1963). Esker deposits are commonly more than 50 feet thick and attain 150 feet in places.

Outwash Deposits

Outwash plains of various sizes are usually associated with eskers, interlobate moraines and end moraines. In the southeastern boundary of the Moose River basin where eskers are numerous, outwash aprons often meet to form extensive sand plains. At the southern tip of the Albany River basin, large outwash plains are associated with interlobate moraines. Small outwash plains are located in the Nakina and the Timmins areas.

Outwash deposits consist generally of sand with minor amounts of gravel. Fine sand may be found in local depressions. Thicknesses of outwash deposits vary from 30 feet in the central parts of the plains to less than a foot in the fringe areas.

Lacustrine Deposits

Surficial lacustrine deposits occur predominantly within the Lacustrine Plain physiographic subregion. Shallow-water deposits of fine to medium sands are found extensively along the southern periphery of the subregion. Deep-water deposits of clay and silt are extensive in the northern part.

In addition, there are small lacustrine sand areas along the southeastern boundary of the Upland subregion and small lacustrine clay areas occur within the Till Plain in the northwest. Pockets of lacustrine clay are found in low depressions throughout the Shield Region.

Marine Deposits

Marine deposits constitute the greatest volume of post-glacial sediments in the Hudson Bay and James Bay lowlands. The bulk of the sediments were deposited on the floor of the Tyrell Sea and consist of clays and silts. Thicknesses range from 10 to 35 feet.

Sand and gravel facies were deposited during the recession of the Tyrell Sea. These materials are found in beach ridges and spits which are abundant in the coastal areas.

Aeolian Deposits

Loess-like aeolian deposits occur as a thin cover over till in a large area at the southern tip of the Albany River basin. Maximum thickness of the deposits is about 4 feet, and the average thickness is less than 2 feet (Zoltai, 1965).

HYDROGEOLOGY

INTRODUCTION

Hydrogeologic information presented in this report has been obtained primarily from field investigations by the former Ontario Water Resources Commission and the Canada Department of the Environment, during the period from 1968 to 1972 and from water-well records up to the end of 1972.

Field investigations entailed measuring exposed geologic sections, sampling overburden deposits, seismic surveying, test drilling and hydraulic testing. Data from these investigations, descriptions of measured geologic sections, mechanical analyses, and (laboratory) permeabilities of overburden samples, have been published in MOE Water Resources bulletins 1-1 through 1-5. In situ injection tests and logs of approximately 90 test holes in bedrock have been published by the Canada Department of the Environment (1972).

Water wells in the study area are few and irregularly distributed (Map 5). Of the 2080 wells in the study area at the end of 1972, 1360 wells penetrate into crystalline rocks, 40 wells into sedimentary rocks, and 680 wells into overburden aquifers (Table 1). Eighty-nine percent of all wells are located in the Moose River basin, about nine percent in the Albany River basin, and the remaining two percent in the Attawapiskat, Winisk and Severn river basins. Wells are located predominantly in the southeastern parts of the study area and generally clustered in the Cochrane-Timmins area and along the northern route of the Trans-Canada Highway between Hearst and Cochrane. In the high density areas such as towns or cities, only selected wells are shown on Map 5.

DISTRIBUTION OF AQUIFERS

The lithologic character, distribution and structure of materials found in northern Ontario control the occurrence, movement, and availability of ground water. On the basis of hydrogeologic significance, the numerous bedrock formations and overburden deposits are grouped into ten aquifer units as shown on Map 4. The units reflect, in many cases, the distribution of geology at depth. Cross sections indicating depths, thicknesses, and sequences of hydrogeologic units are used to supplement information on this map. Aquitard units, which are usually significant in controlling ground-water movement, can be identified in cross sections but not on the map.

In general, northern Ontario can be divided into two major ground-water regions:

a. areas south of the Precambrian-Paleozoic contact which correspond to the Shield Region;
b. areas north of the Precambrian-Paleozoic contact which correspond to the Hudson Bay Lowland Region.

In the Shield Region, the distribution of aquifers is complex (Map 4). Three hydrogeologic areas, however, are apparent and in general correspond to the three physiographic subregions:

Table 1. Water-Well Records for Northern Ontario at the End of 1972

Basin	Number of Wells: Crystalline Rocks	Number of Wells: Sedimentary Rocks	Number of Wells: Overburden	Total	% of Total
Moose	1218	9	620	1847	89.0
Albany	107	31	43	181	8.7
Attawapiskat	12	-	11	23	1.0
Winisk	13	-	1	14	0.5
Severn	10	-	5	15	0.8
All Basins	1360	40	680	2080	100.0
% of All Basins	65	2	33	100	

a) in the general area that corresponds to the Upland Area, wells obtain water primarily from crystalline rocks because overburden deposits, mainly of sand till, are generally thin or absent;

b) in the general area that corresponds to the Lacustrine Plain, overburden deposits are the principal aquifer materials;

c) in the general area that corresponds to the Till Plain, wells obtain water primarily from crystalline rocks because overburden deposits are predominantly aquitards composed of clay till and clay.

There are four types of overburden materials (lithologic units) that form aquifers (Map 4). Two of the four units consist of sand and gravel: sand and gravel in eskers, and sand and gravel related primarily to outwash deposits. The third unit consists of fine to medium sand of primarily lacustrine origin and is referred to hereafter as sand (or sand aquifers). The fourth unit consists of sand till related primarily to end and interlobate moraines. Sand and gravel in eskers and outwash plains offer the greatest potential for high-capacity wells.

In the Hudson Bay Lowland Region, Paleozoic rocks (hereafter referred to as sedimentary rocks) are the principal aquifer materials because the overburden consists predominantly of poorly permeable clay tills and marine deposits (clays and silts). There are five bedrock units; these units consist of limestone/dolomite, sandstone/limestone, sandstone/siltstone, limestone, and carbonaceous shale. The limestone/dolomite units are the most areally extensive bedrock units and have the greatest potential for high capacity wells.

The hydrogeologic conditions occurring in the Shield and Hudson Bay Lowland regions are generally similar in the five river basins. However, because water-well records are irregularly distributed, these conditions are not always illustrated by cross sections in each basin. Cross sections in the upper Moose River basin (Figure 2) best exemplify general hydrogeologic conditions in the Shield Region; those in the lower Moose (figures 3 and 4) and lower Albany river (figures 6 and 7) basins best exemplify general conditions in the Hudson Bay Lowland Region. Other cross sections based on a few well records (Attawapiskat, Winisk and Severn river basins) illustrate localized conditions.

Moose River Basin

The distribution of aquifers in the Shield Region of the upper Moose River basin is quite variable. Overburden aquifers, while being the principal aquifers in the region, are not uniformly distributed (Map 4). Sand, gravel and sand till form the principal aquifers. Where the overburden is thin, absent, or poorly permeable, wells obtain water from fractured crystalline rocks. Yields from crystalline rocks, however, are barely adequate for domestic needs.

Principal overburden aquifers are located in the eastern and central areas in the basin. The eastern half of cross section C-D (Figure 2 in case pocket) shows that sand and gravel deposits are thick and extend over large areas between Kapuskasing and Cochrane. Best aquifers consist of thick sand and gravel deposits in eskers and bedrock valleys. Municipal wells (#927 and #167, not on section lines) in buried gravel aquifers at Kapuskasing and Cochrane, which yield more than 200 gpm per well, are examples of the potential of sand and gravel aquifers, in places.

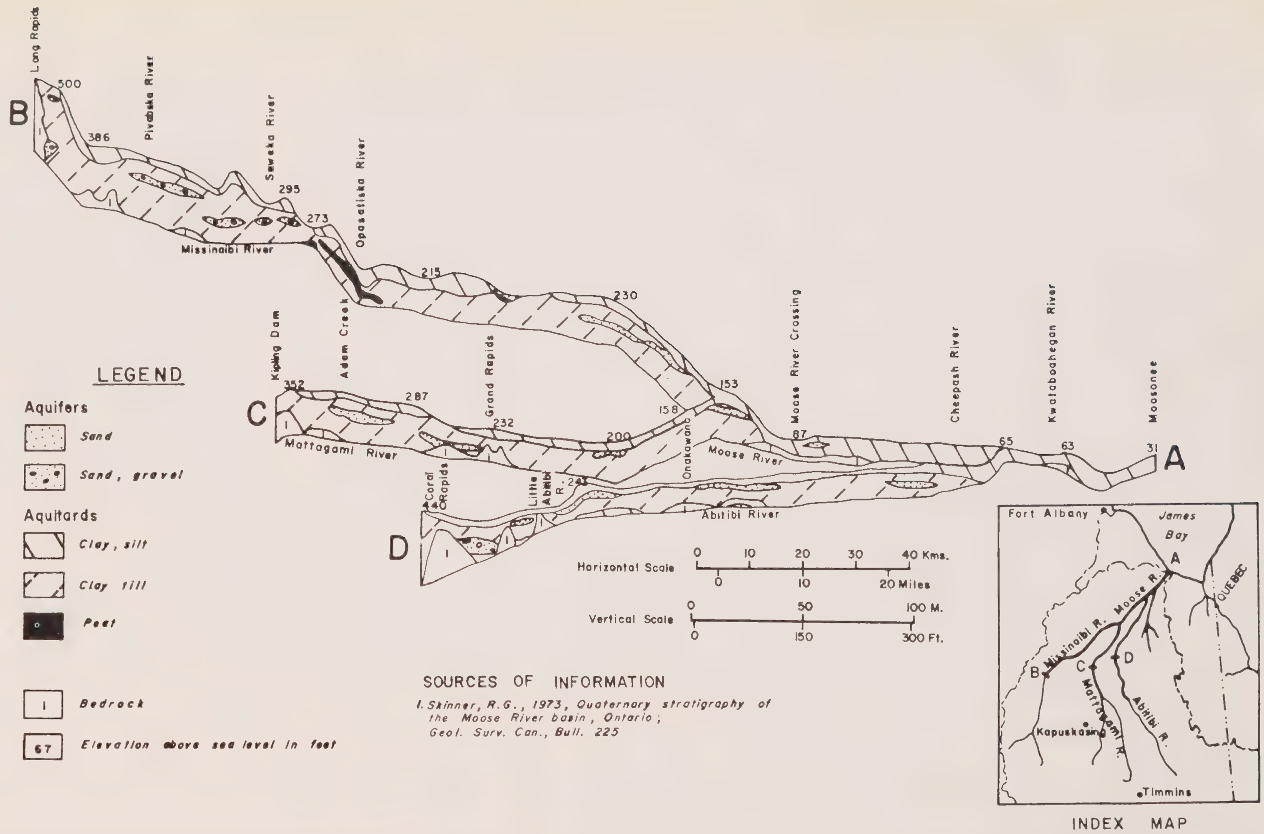


Figure 3. Schematic fence diagram showing overburden hydrogeologic units, lower Moose River basin(modified after Skinner, 1973) .

Cross section E-F between Cochrane and Matheson and cross section G-H between Timmins and Matheson (Figure 2) show that ground water in sand and gravel aquifers is generally confined by overlying clay and clay till, but becomes unconfined in the Nighthawk Lake area. The deposits shown on cross section G-H, in conjunction with the outcrop of outwash deposits to the southeast and continuous with the Nighthawk Lake area (Map 3), indicate that sand and gravel aquifers are areally extensive in the Nighthawk Lake-Matheson area.

In areas close to and along the Precambrian-Paleozoic contact, wells generally obtain water from crystalline rocks because the overburden generally consists of poorly permeable clay and clay till. The western half of cross section C-D (Figure 2) illustrates this. Sand and gravel aquifers are found locally as thin lenses.

In the southern areas along the boundary of the basin, wells generally obtain water from crystalline rocks because overburden aquifers are thin or absent. Scattered occurrences of sand, gravel and sand till in eskers offer some potential for higher yields. However, while these deposits are locally thick, they are often unsaturated.

In the Lowland Region of the lower Moose River basin, overburden units are predominantly aquitards composed of clay tills and marine clays (Figure 3). Aquifers of sand and gravel are exposed in places along the Abitibi, Mattagami and Missinaibi rivers. These aquifers are generally less than 15 feet thick, although sections up to 50 feet thick have been reported locally (Skinner, 1973).

The principal aquifers in the Lowland Region in the Moose River basin, as in the Lowland Region of the other basins, are found in the limestone/dolomite bedrock (Map 4). In general, the limestone/dolomite immediately underlies the overburden except in the Onakawana area where it is overlain by carbonaceous shale and lignite/clay in addition to the overburden deposits (Figure 4). The carbonaceous shale and the lignite/clay are in places more than 250 feet and 150 feet thick, respectively.

Albany River Basin

General hydrogeologic conditions applicable to the Shield Region in each of the five river basins have been previously discussed. Localized hydrogeologic conditions in this region are illustrated by cross sections through an esker-kame complex, an end moraine, and an outwash plain in the Nakina area. Sections are based primarily on seismic surveys and a few test holes.

Cross section A-B (Figure 5) through an esker-kame complex shows thick and continuous deposits of sand and gravel overlying the bedrock. Water entering the ground often drains rapidly from the upper sections of the ridges. The water table is close to the surface at the edges but more than 100 feet below ground surface in the centre of the ridges.

Overburden deposits in an end moraine shown in the western half of cross section C-D (Figure 5) consists predominantly of buried sand till and exposed sand and gravel. The water table is close to the ground surface at the edges but is about 50 feet below the surface in the centre of the ridges.

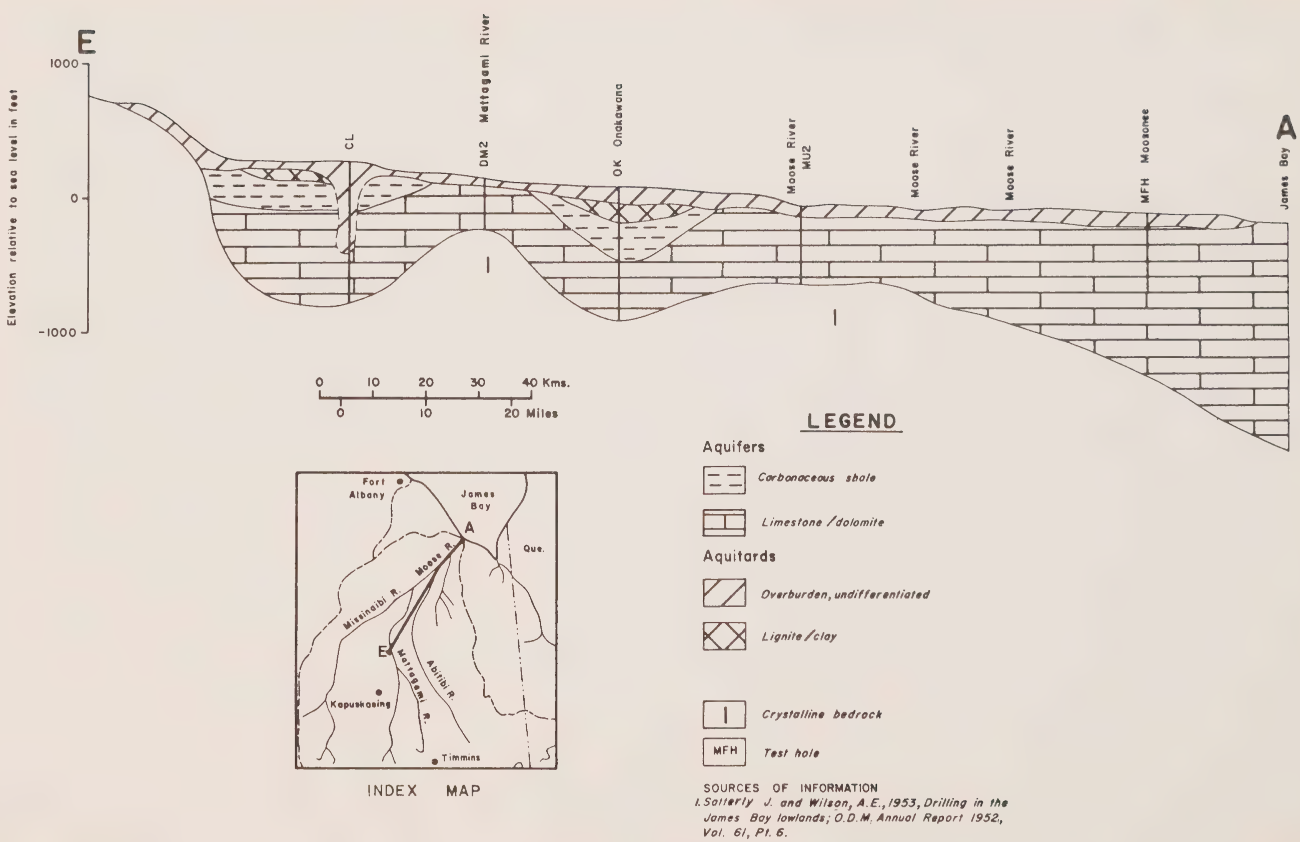


Figure 4. Cross section showing bedrock hydrogeologic units, lower Moose River basin.

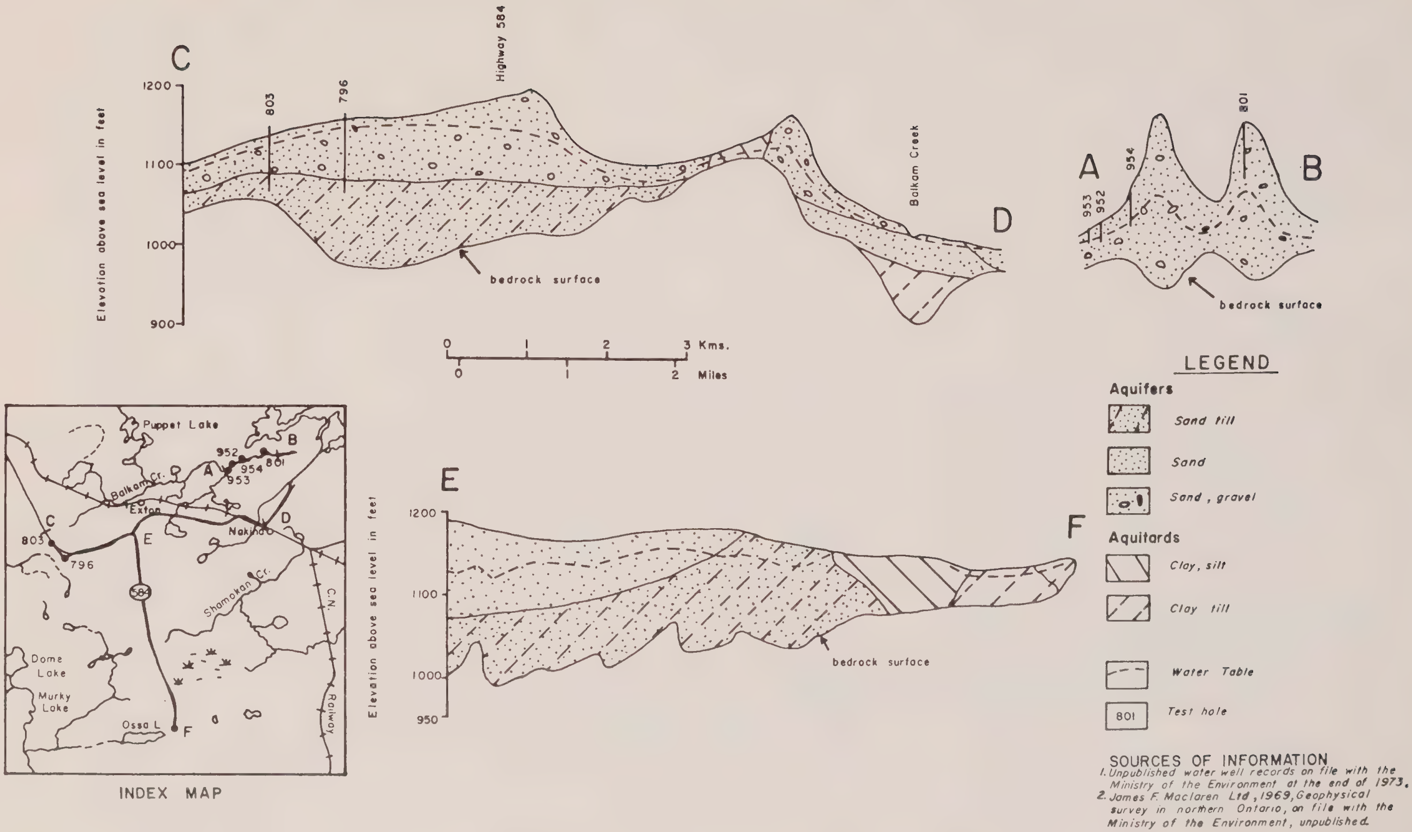


Figure 5. Cross sections showing overburden hydrogeologic units in the Nakina area, upper Albany River basin.

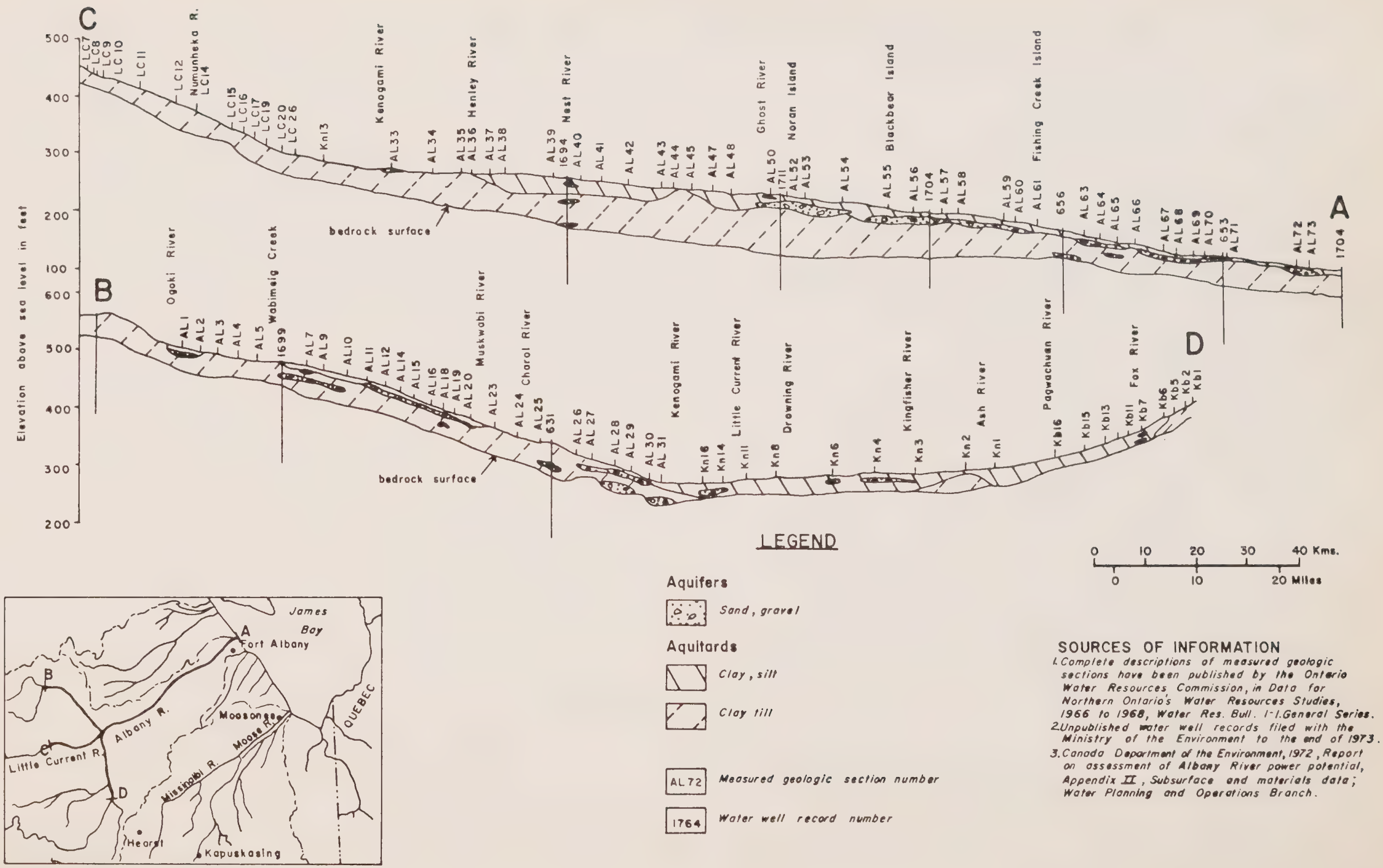


Figure 6. Cross sections showing overburden hydrogeologic units, lower Albany River basin.

Outwash deposits associated with this end moraine are indicated by cross section E-F along Highway 584. Sand tills underlie sands and gravels in the north but outcrop in the central areas. In the south, overburden are predominantly clays, silts and clay tills.

In the Lowland Region of the lower Albany River basin, cross sections of overburden hydrogeologic units (Figure 6) are based primarily on field investigations along the rivers. Aquitards of clay, silt and clay till are the principal overburden materials in this region. The overburden is more than 100 feet thick in the central areas and is 50 to 100 feet thick in the western and coastal areas (cross section C-A). Aquifers consisting of thin layers of sand and gravel occur sporadically in the upper parts of this region (cross section B-D) and become continuous over larger areas along the coast (cross section C-A).

The principal aquifers in the Lowland Region of this basin occur in the limestone/dolomite which immediately underlies the overburden materials (Figure 7). The sandstone/limestone, siltstone/sandstone and carbonaceous shale units underlie the overburden materials in some areas (Map 4 and Figure 7) but these units are not as areally extensive nor as productive as the limestone/dolomite.

Attawapiskat River Basin

Few well records are available in the Attawapiskat River basin and this discussion focuses on local hydrogeologic conditions in the Pickle Lake and Badesdawa Lake areas in the Shield Region, and in the Pym Island area in the Lowland Region. General hydrogeologic settings in these two physiographic regions have been discussed previously.

Overburden materials in eskers in the Shield Region offer generally good potential for high-capacity wells. Cross section A-B (Figure 8) through a broad esker in the Pickle Lake area shows that the bulk of the overburden deposits are sands and gravels in the middle sections of the ridge, with fine to medium sand at the edges and sand till found locally at the base. The water table, which slopes from Graveyard Lake towards Pickle Lake and the Kawinogans River, is more than 50 feet below ground surface in the centre of the ridge and less than 10 feet below ground surface near the river.

Overburden deposits in the Badesdawa Lake area consist primarily of fine sand and sand till (cross section C-D, Figure 9). These deposits are typical of aquifer materials in the central parts of the Shield Region.

In the Pym Island area in the Lowland Region, overburden consists of aquitard materials of clay and silt overlying a uniform fine sand (cross section E-F, Figure 9). Although this sand is water-bearing, there may be difficulty in developing wells that will yield water free of sand. The principal aquifers in this area are the sandstone/limestone which is 10 to 50 feet thick. The distribution of the sandstone/limestone is confined to a long narrow area adjacent to the Precambrian-Paleozoic contact in the Lowland Region (Map 4). This rock unit extends northeast into the Winisk and Severn river basins and southwest into the Albany River basin.

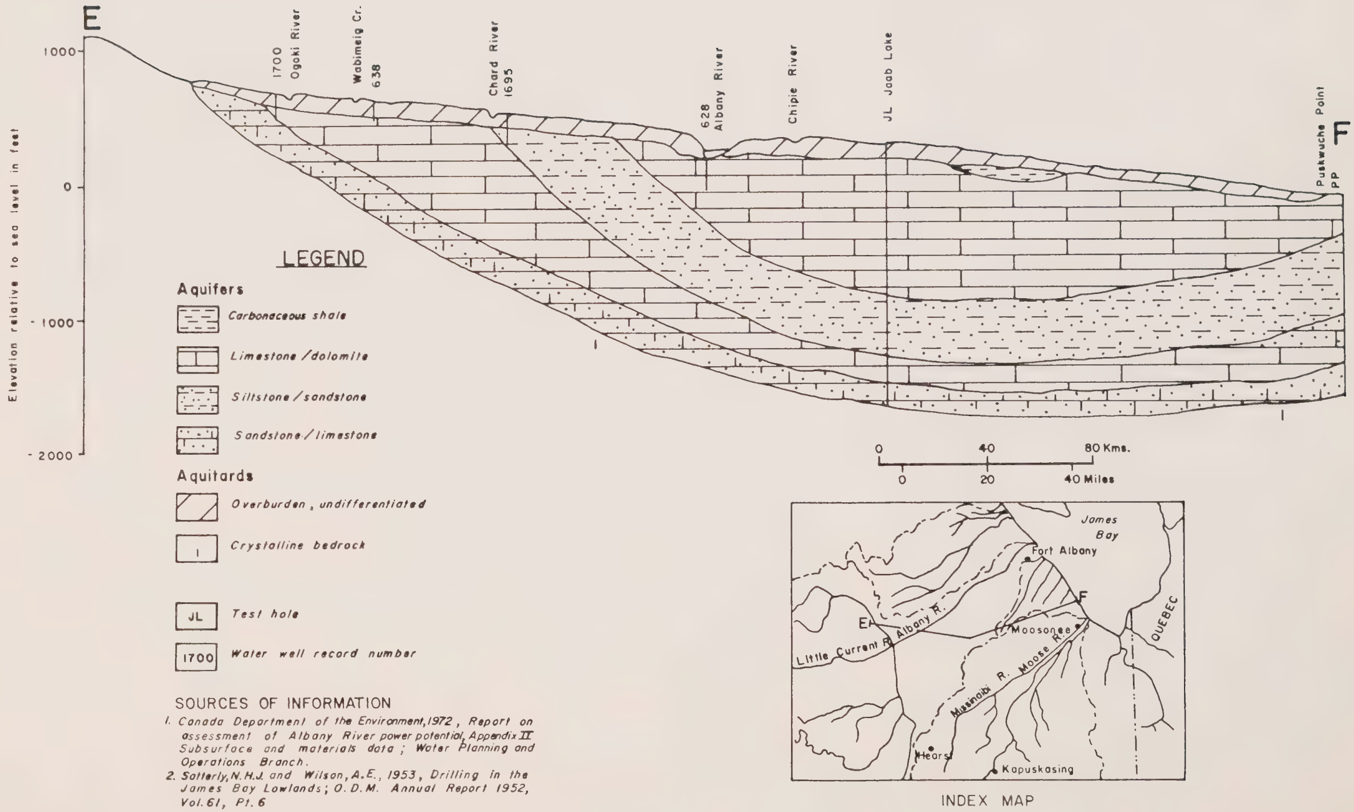


Figure 7. Cross section showing bedrock hydrogeologic units, lower Albany River basin.

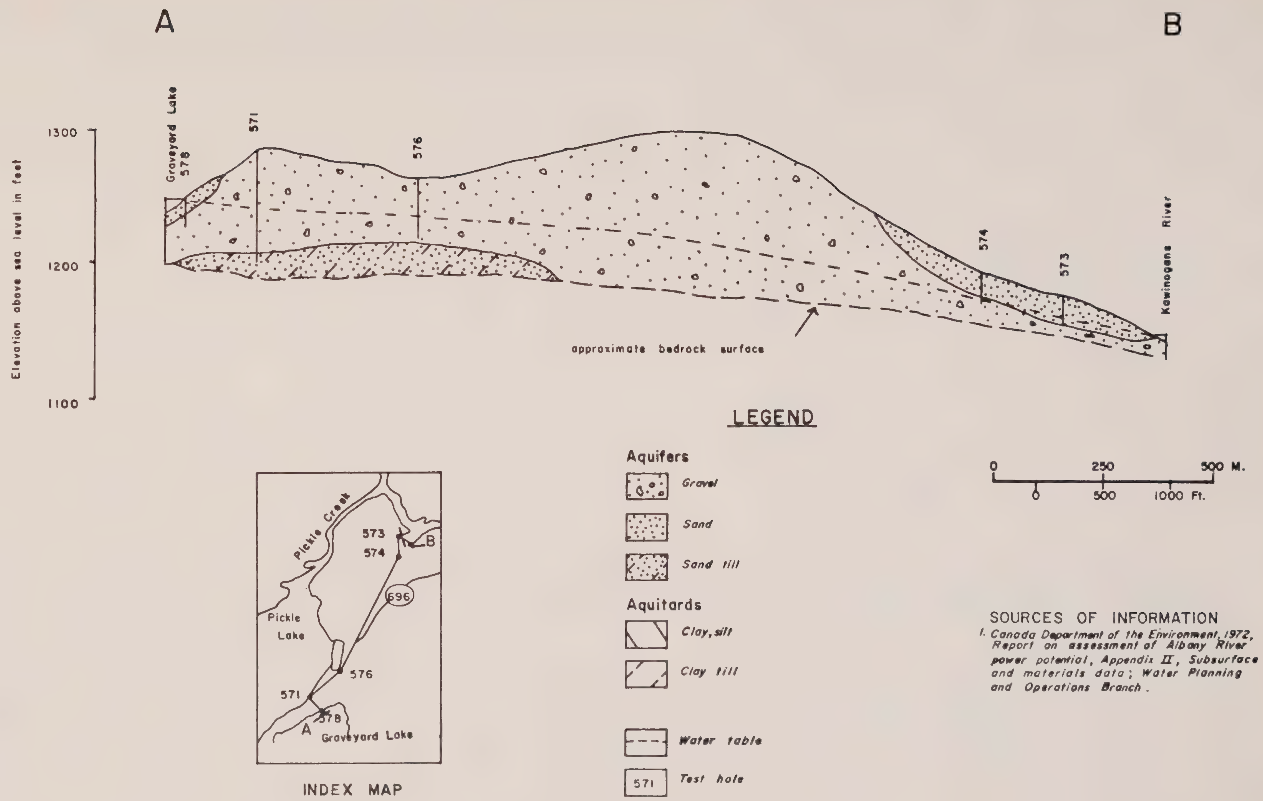


Figure 8. Cross section showing overburden hydrogeologic units in the Pickle Lake area, Attawapiskat River basin.

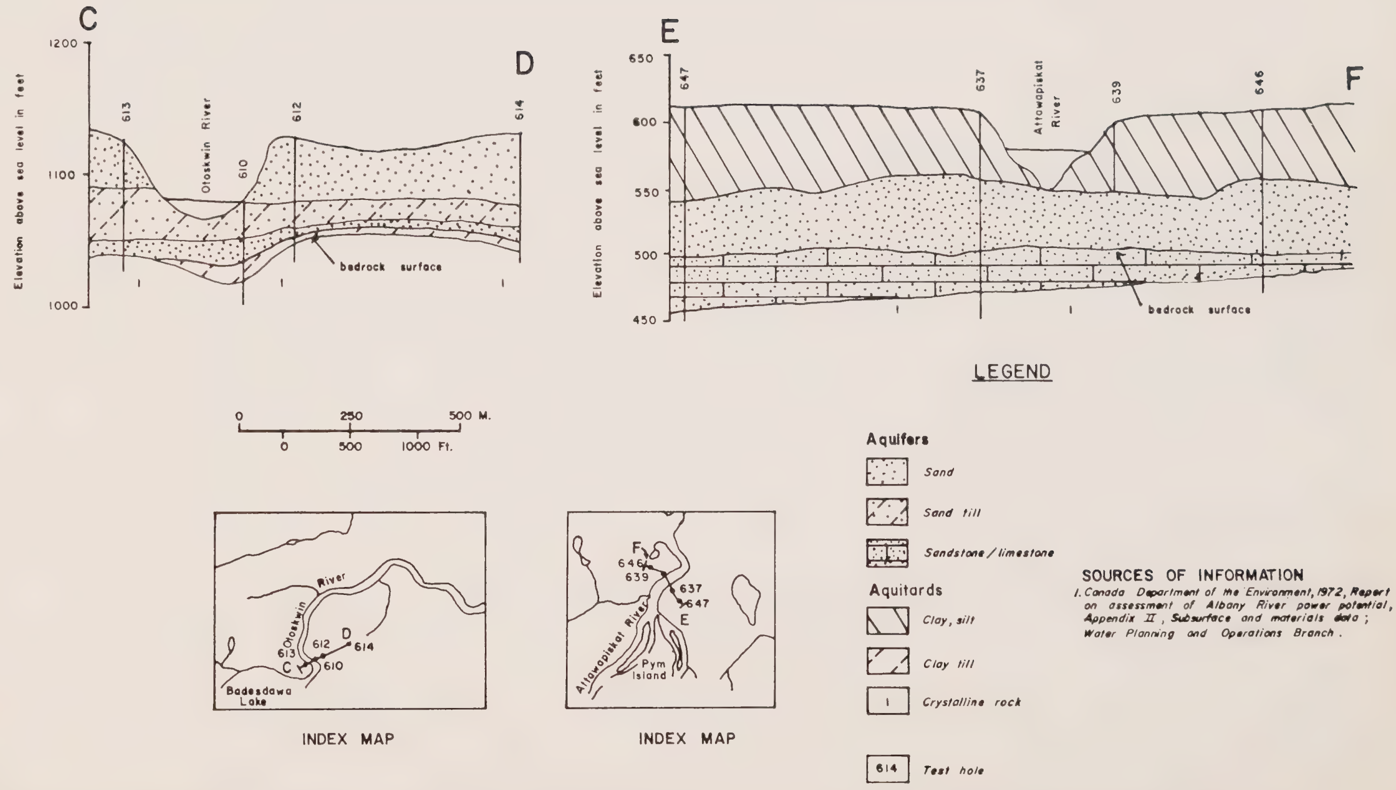


Figure 9. Cross sections showing overburden and bedrock hydrogeologic units in the Badesdawa Lake and Pym Island areas, Attawapiskat River basin.

Winisk River Basin

Few well records are available in the Winisk River basin and cross sections are confined to conditions in the Pipestone River and Winisk Lake areas in the Shield Region. In the Pipestone River area (cross section A-B, Figure 10), a clay till aquitard in the bedrock valley on the east side of the river is overlain by a thick layer of fine to medium sand. This sand is overlain by sands and gravels on the western bank. In the Winisk Lake area, (cross section C-D, Figure 10) a sand till aquifer overlies the bedrock (crystalline rock) surface. The sand till is overlain by an aquitard of clay till on the east side of the lake and by fine sand on the west side.

Except for areas near the Precambrian-Paleozoic contact, general hydrogeologic conditions are the same in the Winisk River basin as in the other basins. These areas, south of and adjacent to the Precambrian-Paleozoic contact in the Shield Region, contain predominantly sand tills or clay tills overlying crystalline rocks. Where sand tills are predominant, the principal aquifer is in the overburden. Where clay tills are predominant, crystalline rocks are the chief sources of water. Areas to the west in the Attawapiskat River basin and to the east in the Severn River basin have similar conditions.

Severn River Basin

Few water-well records are available in the Severn River basin. Localized hydrogeologic conditions in the Muskrat Dam Lake area in the Shield Region are shown by cross section A-B (Figure 11). This section is based primarily on seismic surveys and supplemental information from three test holes. Sand till aquifers in bedrock valleys are confined by a clay aquitard. Ridges of sand that overlie the confining clay beds are saturated only in the lower sections.

General hydrogeologic conditions in the Severn River basin differ only slightly from those described in previous discussions. An exception occurs in the Shield Region along the southwestern boundary of the basin (Map 4) where bedrock outcrops are extensive and there are only few eskers. The overburden deposits in this area are predominantly lacustrine clays. Corresponding areas in the other basins are usually overlain by thin sand tills and generally contain a fair number of eskers.

HYDRAULIC PROPERTIES OF AQUIFER MATERIALS

The geologic character and hydraulic properties of aquifer units vary widely. The four overburden aquifers shown on Map 4 store and transmit ground water through interstitial openings; the six bedrock units that contain aquifers store and transmit water chiefly through secondary openings developed along fractures.

Particle-size distributions and permeabilities of overburden samples determined in the laboratory have been published in MOE Water Resources bulletins 1-1 through 1-5. Permeability, as used in this report, refers to the coefficient of permeability. A regression equation which allows the determination of permeabilities from the particle-size distributions of overburden samples in the study area is presented later.

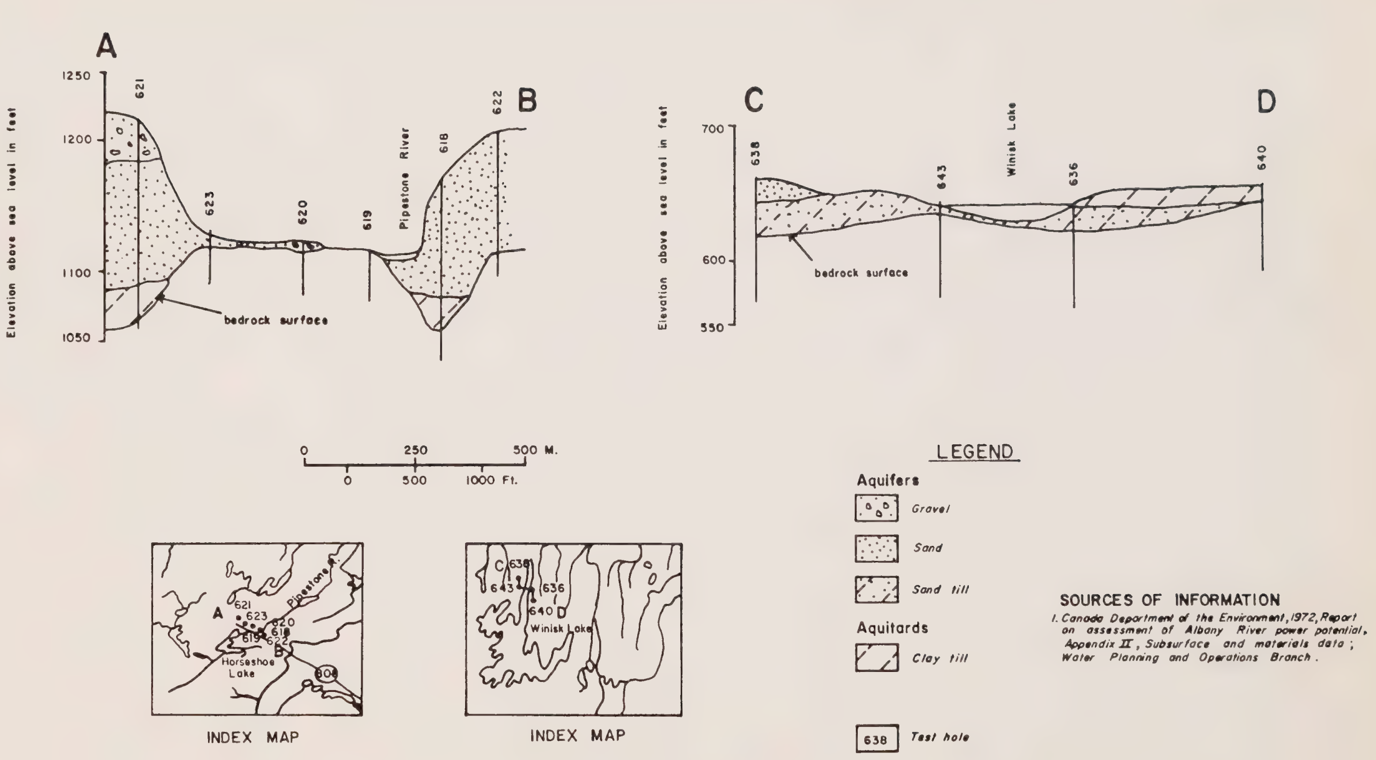


Figure 10. Cross sections showing overburden hydrogeologic units in the Pipestone River and Winisk Lake areas, Winisk River basin.

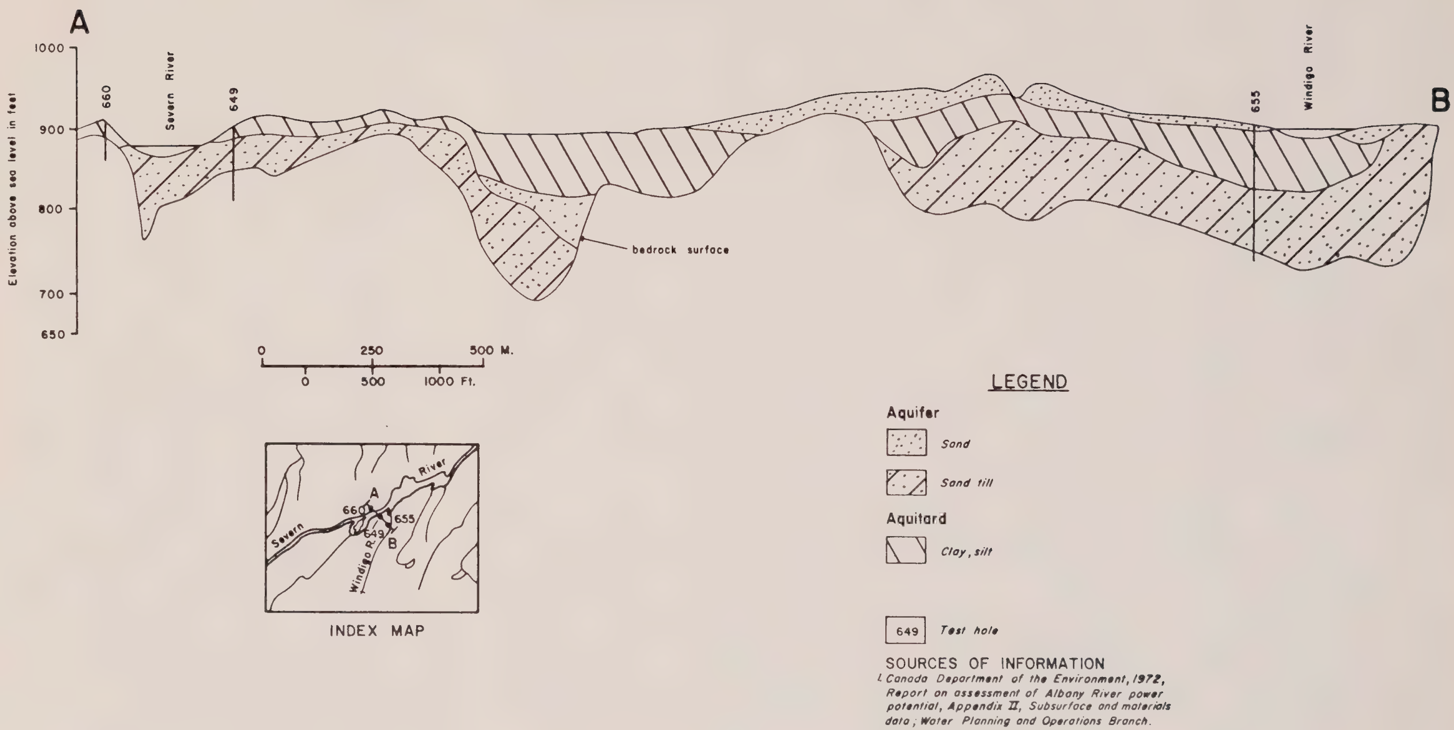


Figure 11. Cross section showing overburden hydrogeologic units in the Muskrat Dam Lake area, Severn River basin.

The size and extent of fractures in bedrock aquifers were inferred from rock core examinations and the percentage of core recovered during test drilling. Permeabilities were determined using Zangar's (1953) equation and data obtained from in situ injection tests (Canada Department of the Environment, 1972).

The presence of open fractures in bedrock varies greatly with location and rock type. Fractures in crystalline rocks are usually closed within 100 feet of the bedrock surface, whereas fracture zones in sedimentary rocks may occur at all depths. Highly fractured sedimentary rocks were found at Campbell Lake where only 76 percent of a drill core was recovered at depths from 700 to 1000 feet below ground surface. In another drill hole at Puskwuche Point, water was found at a depth of 1400 feet below ground surface during core drilling (Satterly, 1953).

Transmissibilities, specific capacities, available drawdowns, and probable yields of wells were determined with the aid of a digital computer from water well records on file with the Ministry of the Environment up to the end of 1972. Equations used in the computations of hydraulic constants are given in Appendix A; drawdown and recovery data from pumping tests are given in Appendix B.

Transmissibilities and specific capacities show log-normal distributions and geometric means are therefore considered representative of average transmissibilities and specific capacities. 'Mean', as used in connection with transmissibilities, specific capacities and other hydraulic constants is in all cases synonymous with geometric mean. 'Average' connotes arithmetic mean.

Specific capacity is the yield of a well in gallons per minute or gallons per day per foot of drawdown. Available drawdown has been taken to be the difference between the static water-level in a well and the top of the screen in a screened well, or the bottom of the casing in an open hole. The estimated maximum yield, hereafter referred to as probable yield, was calculated using Theis' (1935) equation (on the basis of a 6-inch diameter well pumped to the maximum available drawdown over a period of six months). For wells in crystalline rocks, the probable yield was divided by a factor of 2 because fractures in crystalline rocks diminish rapidly with increasing depth below the weathered zone.

Crystalline Rocks

Crystalline rocks refer to all rocks older than the Cambrian. These rocks include metavolcanics, metasediments, and mafic and felsic intrusives of early to late Precambrian Period.

Crystalline rocks are usually highly resistant to weathering and as a result they can be regarded generally as poorly permeable. In some locations in the study area, fractures were observed in rock outcrops. Where overburden is thin, absent, or acts as an aquitard, crystalline rocks are the sole source of ground water.

Transmissibilities of crystalline rocks were determined from the one-drawdown method reported by Ogden (1965) and based on data derived from water-well records. For these calculations, a coefficient of storage of 5×10^{-5} was assumed.

Moose River Basin.... Out of the 1847 wells drilled in the Moose River basin up to the end of 1972, 1218 wells (65 percent) were in crystalline rocks. Nine hundred and thirty-two of these had sufficient data to allow estimates of transmissibilities, specific capacities and probable yields.

Crystalline rocks have a wide range of transmissibilities (Table 2). Transmissibilities range from 1 to 99,000 gpd/ft, the largest value being obtained from well #356 which was pumped at a rate of 1200 gpm with a drawdown of 25 feet. This high value, however, is considered to be unrealistic because the pumping test of 1 hour may be too short a duration for a reliable estimate of the transmissibility. Mean transmissibility of the crystalline rocks in this basin is 210 gpd/ft.

No significant difference (0.05 level) is observed between mean transmissibilities of rock types except between granite plutonic and granite gneiss rocks (Table 3). Mean transmissibilities of granite plutonic and granite gneiss rocks are 343 and 224 gpd/ft, respectively.

Five townships, each with at least 30 wells in crystalline rocks, were selected to indicate the probability of finding water at given depths below the bedrock surface (Figure 12). The frequency distributions are log-normal and generally similar for each of the five townships. Fifty percent of the wells obtain water at depths of 40 to 50 feet or less below the bedrock surface, while 90 percent obtain water at depths of 100 to 150 feet or less. However, wells may penetrate crystalline rocks to considerable depths without obtaining adequate quantities of waters. A total of 81 dry holes, most of which were in crystalline rocks, were reported in the Moose River basin. Well #1107 in O'Brien Township was reported dry to a depth of 867 feet.

The productivity of wells in crystalline rocks in the five townships is indicated by their specific capacities per foot of penetrated rock (Figure 13). The productivity of these wells are generally low. Fifty percent of these wells have specific capacities of less than 3 to 6 gpd/ft (2.1×10^{-3} to 4.2×10^{-3} gpm/ft) per foot of penetrated rock. For the entire Moose River basin, mean specific capacity is 0.14 gpm/ft of drawdown and mean probable yield is 3 gpm (Table 2).

Albany River Basin.... The degree and extent of fractures in crystalline rocks were inferred from rock cores in 16 test holes at Eskawa Falls and Attwood River areas. Core recoveries, which ranged from 97 to 99 percent indicate that crystalline rocks have generally few fractures.

Injection tests on the same holes showed that permeabilities of the rocks vary greatly. In some intervals, water losses amounted to only a few cubic feet per minute (cfm) in response to a hydraulic head of several thousand feet. This indicates few fractures and low permeability. Other intervals in the same area produced water losses at a rate of several cfm in response to a head of less than 50 feet, indicating a highly fractured rock and high permeability.

The rate of water loss to the formation was used to compute permeabilities of crystalline rocks by the formulae devised by Zangar (1953). Average permeability of crystalline rocks in the Albany River basin is less than 2 gpd/ft^2. The values range from 0.05 to 3.4 gpd/ft^2 (Table 4).

Table 2. Transmissibilities, Specific Capacities, Available Drawdowns and Probable Yields of Wells in Crystalline Rocks, Moose River Basin

District	Number of Wells		Transmissibility (gpd/ft)	Specific Capacity (gpm/ft)	Available Drawdown (ft)	Probable Yield (gpm)	Thickness of Rock Penetrated (ft)
Algoma	3	Min.	97	0.06	9	1.0	46
		Max.	2,970	2.3	90	25	89
		Mean	558	0.44	9	3.1	62
Cochrane	900	Min.	8	0.01	1	<1	1
		Max.	99,000	48	527	290	505
		Mean	213	0.14	81	4.0	47
Sudbury	29	Min.	1	0.01	35	<1	2
		Max.	5,340	270	237	57	292
		Mean	104	0.12	84	3.0	51
All Districts	932	Min.	1	0.01	1	<1	1
		Max.	99,000	270	527	290	505
		Mean	210	0.14	80	3.0	47

Table 3. Comparison of Mean Transmissibilities of Rock Types, Moose River Basin

Principal Rock Type	Number of Wells	Mean Transmissibility (gpd/ft)	Comparison of Mean Transmissibility: Between Rock Type	t-Observed	t-Normal	Significant* Difference
1. Granite Plutonic	26	343	1 and 2	-1.709	1.645	Yes
			1 and 3	-1.323	1.645	No
			1 and 4	-0.867	1.697	No
			1 and 5	-1.001	1.684	No
2. Granite Gneiss	194	224	2 and 3	0.956	1.645	No
			2 and 4	0.130	1.645	No
			2 and 5	0.091	1.645	No
3. Gneiss and Schist	181	252	3 and 4	0.201	1.645	No
			3 and 5	-0.320	1.645	No
4. Slates	13	235	4 and 5	-0.032	1.699	No
5. Volcanic and Pyroclastic	21	230				
All Rock Types	435	242				

* Level of significance = 0.05

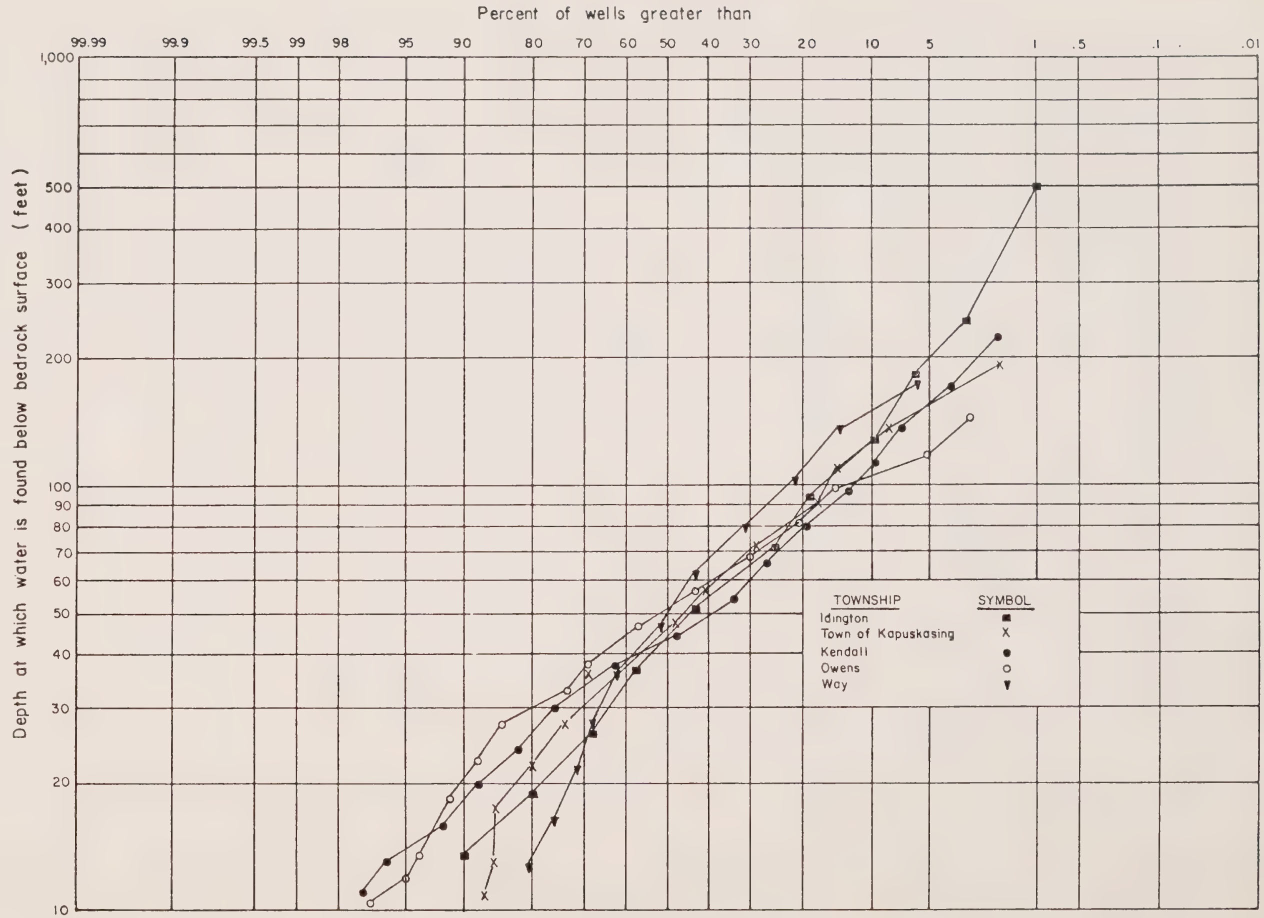


Figure 12. Frequency graphs indicating depths at which water is found below bedrock surface, Moose River basin.

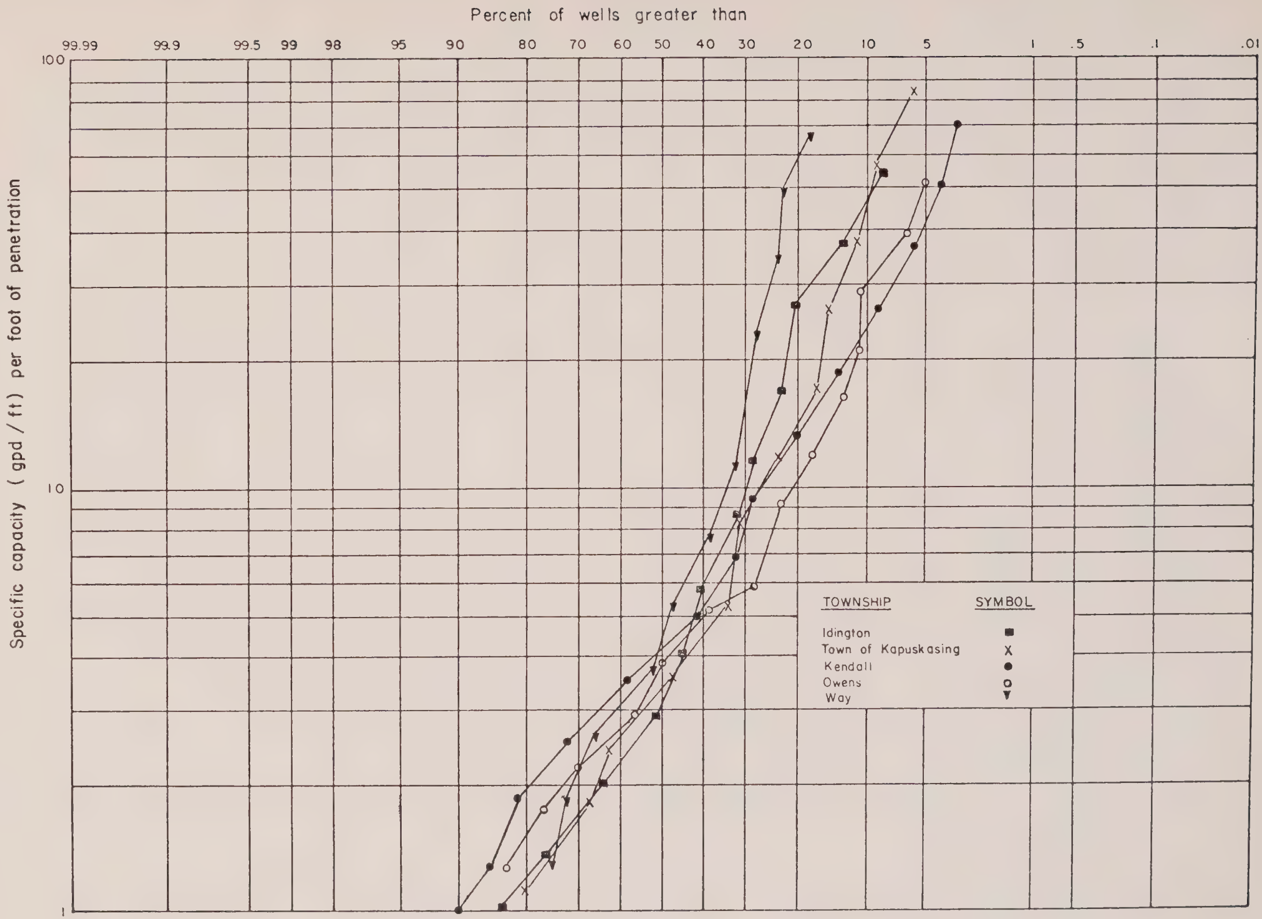


Figure13. Frequency graphs of specific capacities for wells in crystalline rocks, Moose River basin .

Table 4. Summary of Core Recoveries and Permeabilities of Crystalline Rocks.

Basin	Site	Number of Wells Drilled	Total Thickness of Rock Penetrated (ft)	Average Core Recovered (%)	Field Injection Test: Total No. of Tests	Test Length (ft)	Permeability (gpd/ft^2) Range	Average
Albany	Eskawa Falls	8	157	97	2	35	-	0.2
	Attwood	8	217	99	4	98	0.63-3.4	1.4
Attawapiskat	Badesdawa	9	265	98	5	165	0.16-4.4	2.1
	Pym	3	97	80	4	20	0.04-3.0	1.9
Winisk	Pipestone	6	150	92	-	-	-	-
	Last Cedar	4	119	90	6	70	0.04-32	4.8
	Stockman	2	60	91	4	49	0.09-3.4	0.8
	Manson	1	5	100	-	-	-	-
Severn	Muskrat Dam Lake	8	311	98	19	106	0.06-22	3.3
All Basins		49	1391	94	44	543	0.04-32	2.3

Transmissibilities and specific capacities of bedrock wells in the basin were evaluated from 74 water-well records using the method devised by Ogden (1965). Results (Table 5) indicate that the hydraulic properties of rock wells in the Albany River basin are of the same magnitude as those in the Moose River basin. The mean transmissibility and mean specific capacity are low, 200 gpd/ft and 0.12 gpm/ft of drawdown, respectively.

The probability distributions of depths at which water is found below bedrock surface in Algoma and Thunder Bay districts are log-normal and generally similar (Figure 14). Fifty percent of the wells in Algoma and Thunder Bay districts found water at depths of less than 80 feet and 65 feet below bedrock surface, respectively. Specific capacities in Cochrane, Algoma and Thunder Bay districts show some differences (Figure 15). Fifty percent of the wells in the Cochrane District have specific capacities of less than 0.25 gpm/ft of drawdown; less than 0.12 gpm/ft in Algoma, and less than 0.07 gpm/ft in Thunder Bay.

Attawapiskat River, Winisk River and Severn River Basins.... An indication of the degrees of fracturing and permeabilities of crystalline rocks in the Attawapiskat River, Winisk River and Severn River basins was obtained from rock cores and injection tests in 33 test holes at seven sites (Table 4). Rock cores indicated that crystalline rocks contained generally few fractures. Although some fractures were found up to 158 feet below the bedrock surface, most occurred at less than 40 feet below the bedrock surface. Average core recovery from drill holes ranged from 80 percent to 100 percent.

Injection tests in the same holes indicated that the average permeabilities of fractured crystalline rocks in these basins were generally of the same magnitude as those in the Albany River basin (Table 4).

Transmissibilities of fractured crystalline rocks at the Muskrat Dam Lake site in the Severn River basin were calculated from short-term pumping tests on four test holes (#661, #662, #655, and #650). The drawdown and recovery data were analyzed using the formulae by Jacob (1950) and Theis (1935), respectively. Calculated transmissibilities are 100, 400, 480, and 1800 gpd/ft, respectively.

The different transmissibilities obtained for well #661 (100 gpd/ft) and well #650 (1800 gpd/ft) are attributed to differences in the overburden materials at these two sites. In well #661, the crystalline rock is overlain by poorly permeable clay till, whereas in well #650, the crystalline rock is overlain by a more permeable sand till. The high transmissibility of well #650 reflects, most likely, the combined transmissibility of the crystalline rock and the sand till aquifer (which may be providing some water to the well).

Limestone

The limestone bedrock occupies a small area southwest of Onakawana in the Moose River basin (Map 4). No hydrogeologic datum is available for this unit; however, its hydraulic properties are considered to be similar to properties of the limestone/dolomite unit.

Table 5. Transmissibilities, Specific Capacities and Depths Below Bedrock Surface at which Water is Found in Crystalline Rocks, Albany River Basin

District	Number of Wells	Transmissibility (gpd/ft)		Specific Capacity (gpm/ft)		Depth Water Found Below Bedrock Surface (ft)	
		Range	Geom. Mean	Range	Geom. Mean	Range	Average
Algoma	27	9-2800	230	0.03-2.0	0.13	13-387	65
Thunder Bay	33	12-1500	115	0.01-1.3	0.07	8-190	80
Cochrane	17	68-3700	400	0.04-2.0	0.25	11-240	65
All Districts	77	9-3700	200	0.01-2.0	0.12	8-387	71

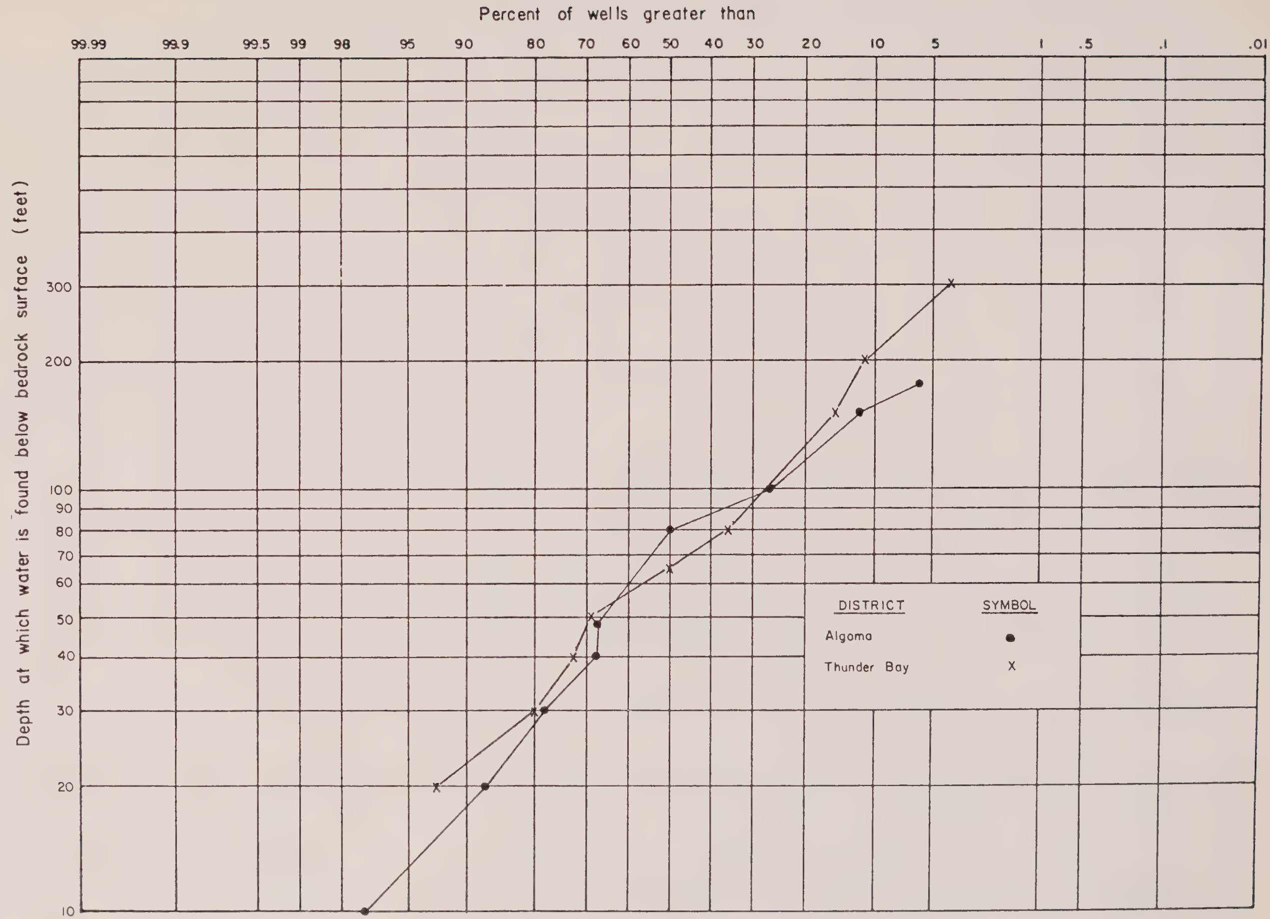


Figure 14. Frequency graphs indicating depths at which water is found below bedrock surface, Albany River basin.

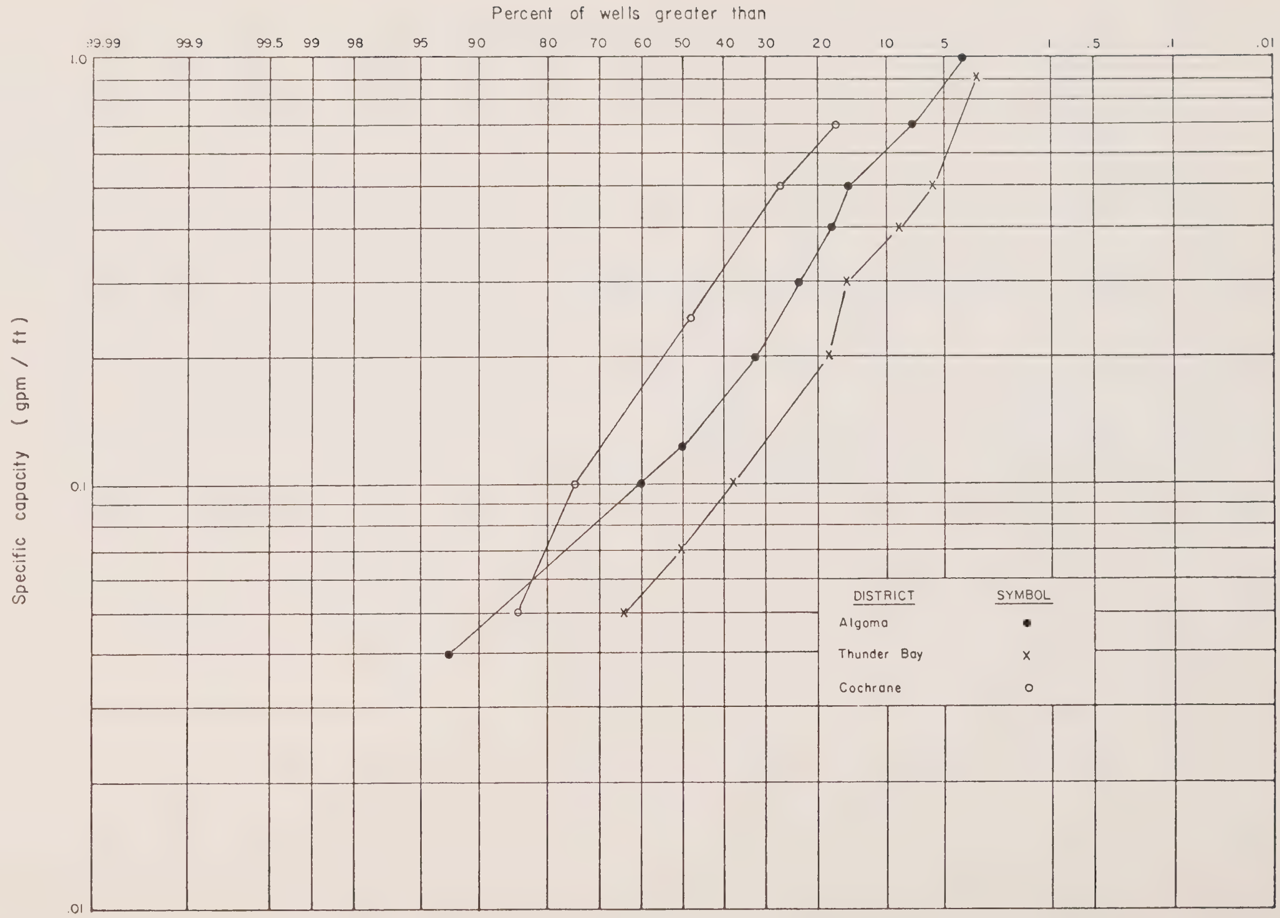


Figure 15. Frequency graphs of specific capacities for wells in crystalline rocks, Albany River basin .

Limestone/Dolomite

The limestone/dolomite bedrock is approximately 45,000 square miles in area and is the largest bedrock unit underlying the overburden in the Lowland Region. Included in this category are the formations of Churchill River, Severn River, Ekwan River, Attawapiskat River, upper and lower Kenogami rivers, Stooping River, Moose River, Murray Island and William Island. These formations are generally saturated except in the vicinity of outcrops at the southern boundary where they may be unsaturated in the upper sections.

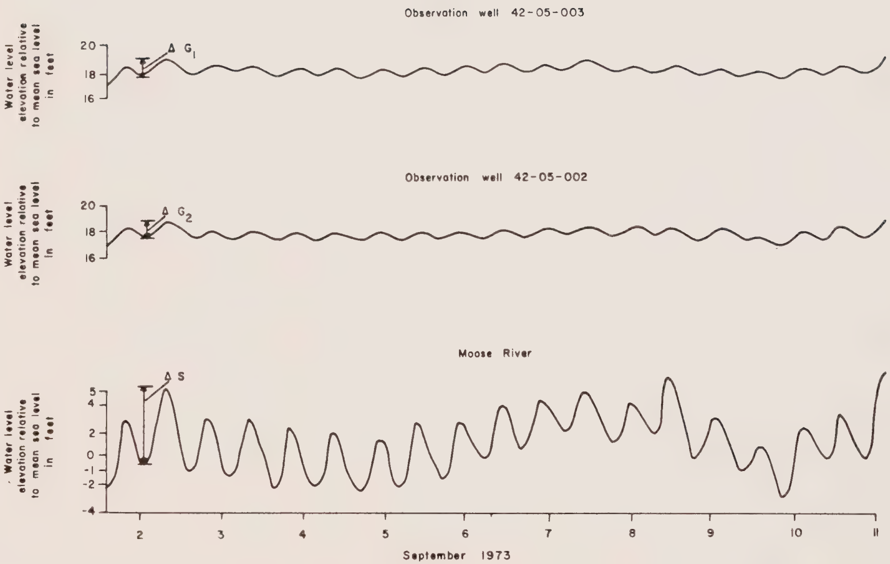
There are less than 50 well records on file with the MOE for the Lowland Region. Most of these records are of test holes drilled by the Canada Department of the Environment and the Ontario Ministry of the Environment. The hydraulic data obtained from these holes indicate the limestone/dolomite to be generally highly productive.

Moose River Basin.... Information about the limestone/dolomite in the coastal area in this basin was obtained from 5 test holes drilled in Moosonee. Hydraulic properties of aquifers were obtained from short-term pumping tests on wells #1759 and #1760 (observation wells #42-05-003 and #42-05-002). Water levels for these two wells show cyclic fluctuations similar to the Moose River (Figure 16). After corrections for tidal effect on the drawdowns, semi-log plots of the drawdowns were used to calculate transmissibilities of 5300 gpd/ft and 13,200 gpd/ft.

Representative values of the coefficient of storage and transmissibility of the limestone/dolomite were computed using methods by Jacob (1953) and Ferris (1951). The changes in ground-water stage (ΔG_1 and ΔG_2) divided by the change in river stage (ΔS) during the period from September 2nd to September 11th, 1972, were computed for the rising limb of each cycle of the three hydrographs (Figure 16). A semi-log plot (Figure 17) of the average stage ratios $\Delta G_1/\Delta S$ and $\Delta G_2/\Delta S$ versus the distance to the river gave a tidal efficiency of 0.24 at the river-edge.

Assuming the effective porosity to be 2 percent and the thickness of the aquifer in the coastal area to be 100 feet, the coefficient of storage computed from the tidal efficiency using Jacob's equation was 4×10^{-6}. The average period corresponding to half the water-level cycle was 0.5 day (Figure 16) and the distance corresponding to one log-cycle of stage ratio was 20,700 feet (Figure 17). Using these values in Ferris' (1951) equation, a transmissibility of 12,000 gpd/ft was obtained.

Albany River Basin.... The extent of fractures in limestone/dolomite in this basin was obtained from core examinations from logs of approximately 30 test holes drilled along the Albany River. Core examinations suggested that secondary porosity has developed along fractures and joints. Vugs up to one inch in size were found in many cores but none of the cores indicated large cavities. Core recoveries from 23 test holes at 6 sites ranged from 10 to 90 percent of rock drilled. Average core recovery was 62 percent. Drilling fluid was lost rapidly on occasion; the abruptness of fluid loss suggests the presence of large open fractures.



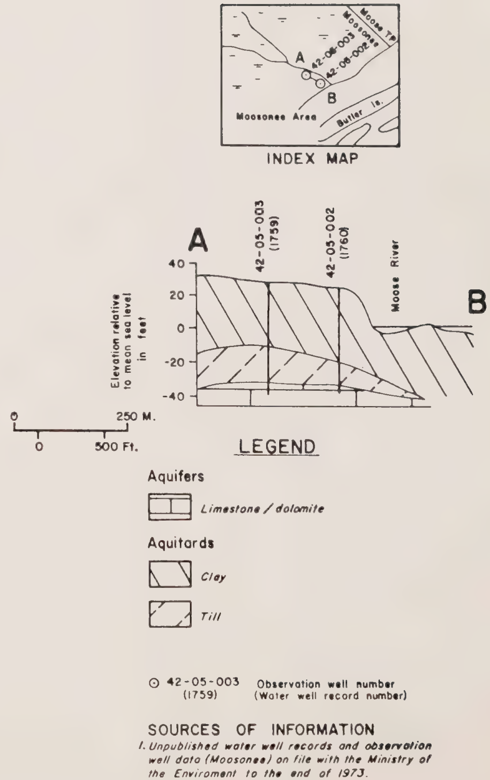


Figure 16. Water-level hydrographs for the Moose River and for two observation wells in Moosonee (Sept. 2-11, 1973), Moose River basin.

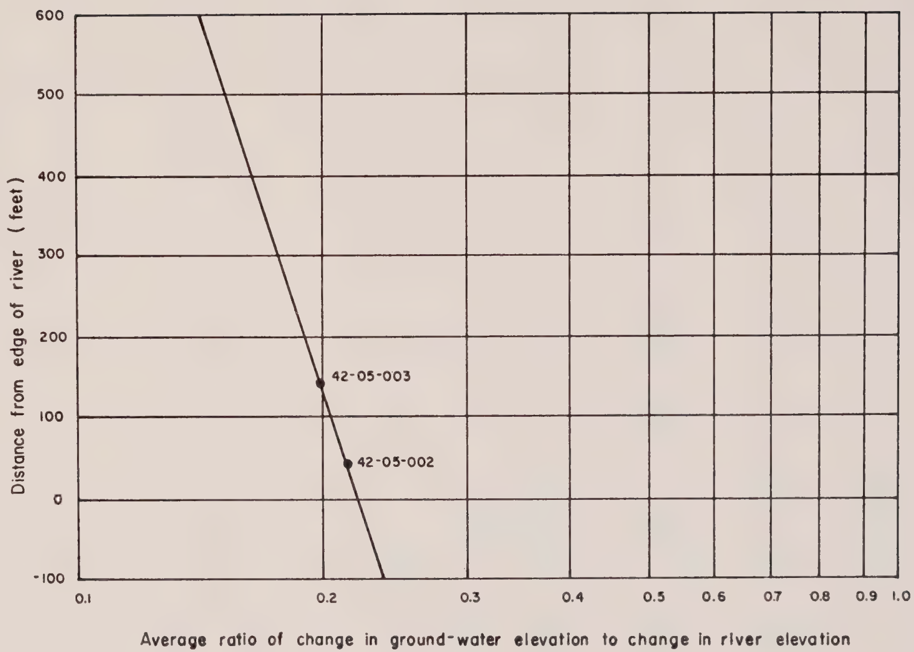


Figure 17. The average ratio of change in ground-water elevation to change in elevation of the Moose River versus the distance of the observation well from the river .

Table 6. Results of Field Injection and Pumping Tests on Test Holes in Limestone/Dolomite, Albany River Basin

Well No.	Total Thickness of Rock Penetrated (ft)	Field Injection Test: Total No. of Tests	Field Injection Test: Test Length (ft)	Field Injection Test: Permeability (gpd/ft^2) Range	Field Injection Test: Permeability (gpd/ft^2) Average	Pumping Test: Transmissibility (gpd/ft)	Pumping Test: Coefficient of Storage
627	4	-	-	-	-	490	
628	146	1	65	-	13	-	
629	54	2	22	-	1.0	-	
1694	98	1	67	-	0.6	-	
1698	60	1	7	-	0.06	-	
630	153	1	20	-	12	-	
633	91	2	50	-	3.2	-	
634	38	1	19	-	5.8	1600	$1.3x10^{-4}$
635	26	1	6	-	32	-	
1699	125	1	14	-	9.0	-	
1701	140	9	92	0.3-26	14	1500	
1711	65	1	18	-	20	-	
1709	66	-	-	-	-	13200	
664	17	1	6	-	8.0	-	
656	101	-	-	-	-	36000	
1708	72	4	22	6-16	9.0	6000	
648	120	18	100	7-56	23	13200	
1703	130	11	69	0.1-52	17	4400	
1705	91	11	66	0.5-32	15	12700	
1704	46	4	31	5-55	16	5570	
651	38	2	11	-	30	9300	
All Wells	1722	72	685	0.1-56	10	5300	

The permeabilities of aquifers in the limestone/dolomite were determined from data of in situ injection tests conducted in 18 test holes at 7 sites (Table 6). The rates of water loss in these aquifers ranged from less than 1 cubic foot per minute (cfm) in response to a hydraulic head of 140 feet, to more than 1 cfm in response to 30 feet of head. Data from injection tests were used to calculate permeabilities by the formula devised by Zangar (1953). Results (Table 6) indicate that the limestone/dolomite rocks are generally fractured. Permeabilities range between 0.1 and 56 gpd/ft^2 with an average of 10 gpd/ft^2.

Transmissibilities of the limestone/dolomite were obtained from short-term pumping tests conducted in 11 test holes at 5 sites. These values were estimated on the basis of the formulae devised by Jacob (1950) and Theis (1935). The coefficient of storage was determined according to Lohman (1963).

Transmissibilities range between 490 gpd/ft and 36,000 gpd/ft with a mean of 5300 gpd/ft. Based on this mean value, it is estimated that individual wells in limestone/dolomite may yield up to 200 gpm.

A representative value of the transmissibility in the Hat Island area (observation well #43-05-004, well #627) was determined from the drain function method by Stallman (1962). The water level recession curve shown in Figure 18 was matched to a type curve. Using the coefficient of storage of 1.3×10^{-4} from the pumping test, a transmissibility of 2700 gpd/ft was obtained. This is much greater than the transmissibility of 490 gpd/ft obtained from the analysis of pumping test data by Jacob's (1950) method. The reason for this difference is probably due to the effective radius represented by the different methods. The effective radius of the Stallman method is much greater than that of the Jacob method. Therefore, the larger transmissibility value is representative of a larger aquifer area whereas the smaller value is representative of localized conditions.

Sandstone/Limestone

The sandstone/limestone bedrock underlies approximately 4700 square miles of overburden in the Lowland Region. The bedrock consists of Ordovician undivided and the Bad Cache Rapids Group. The unit is approximately 50 feet thick and is underlain by Precambrian rocks.

Data relevant to aquifers in the sandstone/limestone were obtained from six test holes drilled at Buffaloskin site in the Albany River basin and the Pym Island site in the Attawapiskat River basin. Many of the recovered rock cores were badly broken. Core examinations at these sites suggest that secondary openings formed by the dissolution of carbonate along joints and fractures are abundant. Vugs up to 1/2-inch in diameter were found in many cores. Average core recovery was 65 percent, suggesting a highly fractured rock.

Aquifer permeabilities were determined from in situ injection tests conducted on test holes #657 and #1700. These permeabilities ranged from less than 0.1 to 30 gpd/ft^2, with an average of 4 gpd/ft^2 (Table 7). This is about one-third of the average permeability obtained for the limestone/dolomite.

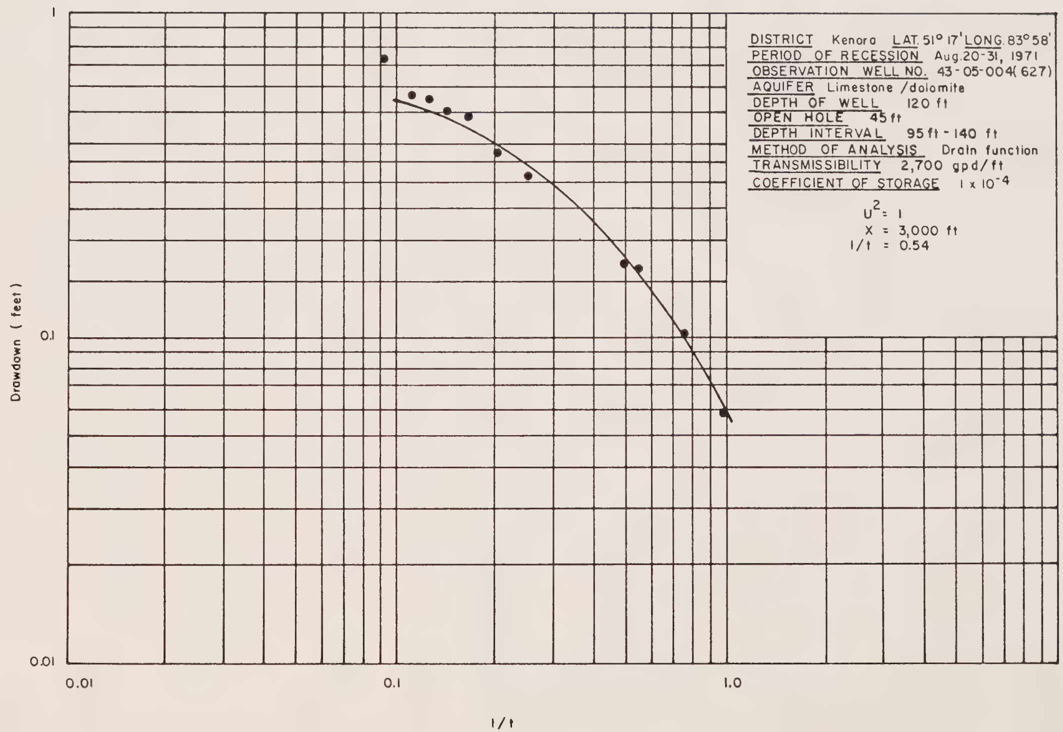


Figure 18. Water-level recession curve for observation well no. 43-05-004 in a limestone / dolomite aquifer following a rise in stage of the Albany River, Hat Island.

Table 7. Results of Field Injection Tests on Test Holes in Sandstone/Limestone

Well No.	Total Thickness of Rock Penetrated (ft)	Field Injection Test			
		Total No. of Tests	Test Length (ft)	Permeability (gpd/ft^2) Range	Average
657	128	4	102	0.17-30	3
1700	64	6	50	0.06-4	5
All Wells	192	10	152	0.06-30	4

Table 8. Results of Field Injection and Pumping Tests on Test Holes in Sandstone/Siltstone

Well No.	Total Thickness of Rock Penetrated (ft)	Field Injection Test				Pumping Test
		Total No. of Tests	Test Length (ft)	Permeability (gpd/ft^2) Range	Permeability (gpd/ft^2) Average	Transmissibility (gpd/ft)
1706	143	8	72	0.9-19	5.5	
653	134	2	22	-	11	410
1707	32	3	20	3-25	13	
1695	140	16	80	0.22-110	35	
1696	39	3	11	0.09-0.36	0.3	
1697	122	10	48	0.17-4.7	1.6	
632	119	4	67	0.29-1.6	0.9	
631	170	7	32	0.15-6.3	2.0	
All Wells	899	53	352	0.09-110	11	

Since no pumping tests were carried out on these holes, the transmissibility values were estimated on the basis of permeabilities and the total thicknesses of rock penetrated. The transmissibility thus obtained was 450 gpd/ft which is smaller than the value for aquifers in limestone/dolomite. Based on this value, it is estimated that individual wells in sandstone/limestone may yield up to 25 gpm.

Sandstone/Siltstone

The sandstone/siltstone bedrock underlies the drift covering an area of approximately 3600 square miles in the Lowland Region. The principal geologic formation is the middle member of the Kenogami River Formation.

Cores obtained from 8 drill holes at the Chard and Biglow sites in the Albany River basin indicated the rocks to be calcareous with interbeds of limestone and dolomite. Secondary openings have developed by dissolution of carbonate from the rocks. Rock cores recovered from drill holes were generally badly broken indicating the presence of many openings in the rock. Vugs of 1/4- to 1/2-inch in size were found in several core samples. Core recovery ranged from 26 to 87 percent and averaged 58 percent.

Permeabilities of aquifers in sandstone/siltstone determined from injection tests (Table 8) indicate that the sandstone/siltstone is generally as permeable as the limestone/dolomite, with permeabilities ranging from less than 0.1 to 115 gpd/ft^2. Average permeability is 11 gpd/ft^2.

Transmissibilities of the aquifers vary greatly. A transmissibility of 410 gpd/ft was computed using Jacob's formula and data from a short-term pumping test conducted on test hole #653 at the Biglow site. Another value of 2800 gpd/ft was determined on the basis of permeability and tested length for test hole #1695 at the Chard River site (Canada Department of Environment, 1972). Based on the transmissibility value obtained from the pumping test, it is estimated that individual wells in sandstone/siltstone may yield up to 25 gpm.

Carbonaceous Shale

The carbonaceous shale is of small areal extent and involves the Long Rapids Formation at the southeastern part of the Lowland Region. No information was available regarding the hydraulic properties of aquifers in this Formation.

Overburden

Aquifer materials in overburden have a wide range of grain size and sorting, both of which are important factors affecting permeabilities. Approximately 150 overburden soil samples were collected throughout the study area during the period from 1968 to 1972. Grain-size distributions and permeabilities of the samples were determined in the laboratory and results of these and the locations of samples have been published in Water Resources bulletins 1-1 through 1-5.

The correlations of particle sizes to interstitial permeabilities of all the overburden samples were made using a simplified stepwise regression procedure devised by Mount and Lund (1963). A regression formula that has a 75 percent reduction of variance was obtained and is as follows:

$$\log K = 0.76 \log d_{25} - 0.28w + 0.15 \log d_{50}^2$$

$$- 3.1 \log d_{75}^2 - 4.0$$

where:

- K = average permeability (cm/sec)
- w = percent clay (0.04 mm) by weight
- d_{25} = particle size (mm) corresponding to 25 percent by weight passing
- d_{50} = particle size (mm) corresponding to 50 percent by weight passing
- d_{75} = particle size (mm) corresponding to 75 percent by weight passing

This formula can be used to estimate the permeabilities of overburden materials provided that the grain-size distributions of the materials are known.

In addition to the laboratory analyses of soil samples, hydraulic properties of some of the main overburden aquifers were also determined from pumping-test data obtained either from water-well records on file with the Ministry of the Environment or from actual field tests. Transmissibilities, specific capacities and probable yields of overburden aquifers in the study area are summarized in Table 10 and discussed by individual basins.

Moose River Basin.... The particle-size distributions and permeabilities of 24 overburden samples are summarized in Table 9. The samples are divided into three categories. The first category consists of sands and gravels that were obtained from fluvial deposits including eskers, kames and raised beach deposits. The second category consists of sand tills that were obtained from end moraines, and the third category consists of sand samples taken from deposits in the Lacustrine Plain and the Lowland Region.

Mean permeabilities of sand tills are the lowest (70 gpd/ft^2). Sands are permeable with a mean permeability of 200 gpd/ft^2 and the sands and gravels have the highest permeability with a mean of 500 gpd/ft^2.

There are approximately 620 overburden wells in the Moose River basin for which water-well records are on file with the MOE. Four hundred and seventy-six of these records contain information on pumping tests which was used to estimate the transmissibilities of the aquifers by the method devised by Ogden (1956). For these calculations, a coefficient of storage of 5×10^{-4} was assumed for a confined aquifer and a specific yield of 0.1 for an unconfined aquifer.

Wells in sand and gravel aquifers are the most productive in the basin (Table 10). Transmissibilities of the sand and gravel aquifers range from 670 to 86,000 gpd/ft with a mean of 5000 gpd/ft. Specific capacities range from 0.2 to 37 gpm/ft and the mean probable yield of individual wells is 270 gpm.

Table 9. Summary of Particle Size Distributions and Permeabilities of Aquifer Materials in Overburden, Moose River Basin

Aquifer Material	Number of Samples	Particle Size (mm)			Sorting Coefficient (d_{75}/d_{25})	Clay Content	Permeability (gpd/ft^2)	
		d_{25} Range	d_{50} Range	d_{75} Range	Range	(%)	Range	Geom. Mean
Sand and Gravel	11	0.45-0.91	0.13-0.25	0.68-5.0	1-4	0	2 - 1200	500
Sand Till	2	0.03-0.12	0.10-0.20	0.20-0.33	1-3	0-4	-	70
Sand	11	0.03-0.25	0.07-0.25	0.38-0.40	1-3	0	4 - 500	200

Table 10. Summary of Transmissibilities, Specific Capacities and Probable Yields of Overburden Aquifers

Basin	Aquifer Lithology	Number of Wells	Transmissibility (gpd/ft)		Specific Capacity (gpd/ft)		Probable Yield (gpm)	
			Range	Geom. Mean	Range	Geom. Mean	Range	Geom. Mean
Moose	Sand and gravel	30	670-86,000	5000	0.2-37	3	26-1000	270
	Sand, sand till	446	140-2840	320	0.05-3	0.3	1-66	15
Albany	Sand and gravel	13	500-38,000	5000	0.3-30	3	10-1000	150
	Sand, sand till	12	60-1700	240	0.04-2	0.2	1-25	6
Attawapiskat and Severn	Sand, sand till	3	500-900	700	0.3-2	1	10-30	20
All Basins	Sand and gravel	43	500-86,000	5000	0.2-37	3	10-1000	200
	Sand, sand till	461	60-2840	500	0.04-3	0.3	1-66	15

No attempt was made to separate wells in sand aquifers from those in the sand till because their hydraulic properties appear to be similar. Results from 446 wells indicated that the sand and sand till aquifers have much smaller transmissibilities and specific capacities than the sand and gravel aquifers. Probable yields of individual wells in sand and sand till aquifers range from 1 to 66 gpm with a mean of 15 gpm.

A comparison of the (statistical) distribution of specific capacities of wells in both confined and unconfined overburden aquifers (Figure 19) shows that the unconfined aquifers have slightly higher specific capacities. Fifty percent of the wells in confined aquifers have specific capacities greater than 0.26 gpm/ft, whereas in unconfined aquifers the corresponding value is 0.35 gpm/ft.

Albany River Basin.... The permeabilites and particle-size distributions of overburden aquifer materials in the Albany River basin were determined in the laboratory for 22 samples collected from various parts of the basin.

Results (Table 11) indicate that sands and gravels in the Albany River basin are usually as permeable as those in the Moose River basin, but samples of sands and sand tills in the Albany River basin are significantly less permeable than those in the Moose River basin.

Transmissibilities of sand and gravel aquifers in the Albany River basin were determined from short-term pumping tests conducted on three test holes (#609, #799 and #800). The transmissibilities computed from Jacob's (1950) equation are 21,000, 38,000 and 21,000 gpd/ft respectively.

The transmissibility of a sand and gravel aquifer in the Precambrian-Paleozoic contact area was determined from water-level records for observation well #43-05-003. According to Rorabough (1961), the ground-water profile near a discharge boundary is considered to be stable when the water table falls exponentially with time and aquifer transmissibility can be computed for this condition. The semi-log plot for this observation well during the period from June 1 to July 1, 1971 (Figure 20) shows that this condition is satisfied and can be used in the determination of transmissibility. The distance from the ground-water divide to the lake and the specific yield of the aquifer were estimated to be 1320 feet and 0.15, respectively. The computed transmissibility of this sand and gravel aquifer is high (23,000 gpd/ft).

The hydraulic properties of 25 other overburden water wells were determined by the drawdown method devised by Ogden (1965). Results (Table 10) indicate that the transmissibilities and specific capacities of overburden wells in the Albany River basin are of the same magnitude as those in the Moose River basin. Mean transmissibilities are 5000 gpd/ft for sand and gravel aquifers and 240 gpd/ft for sand and sand till aquifers.

Probable yields of individual wells are generally less in the Albany River basin than those in the Moose River basin because both the thicknesses of overburden aquifers and the available drawdowns in the Albany basin are generally smaller than those in the Moose River basin. Mean probable yield per well in the Albany basin is 150 gpm in sand and gravel aquifers and 6 gpm in sand and sand till aquifers.

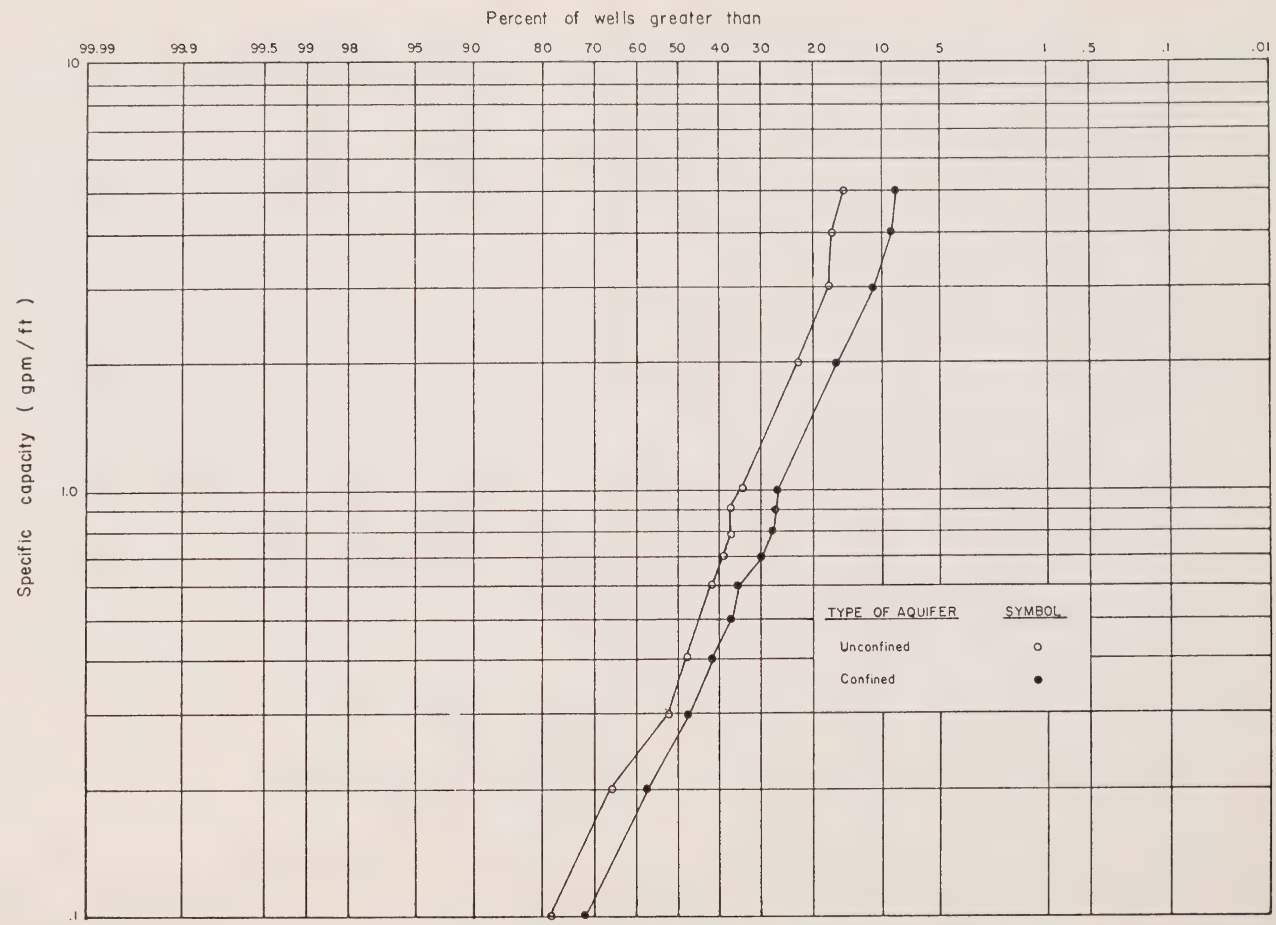


Figure 19. Frequency graphs of specific capacities for wells in overburden, Moose River basin .

Table 11. Summary of Particle Size Distributions and Permeabilities of Aquifer Materials in Overburden, Albany River Basin

Aquifer Material	Number of Samples	Particle Size (mm)			Sorting Coefficient $(d_{75}/d_{25})^{1/2}$	Clay Content	Permeability (gpd/ft^2)	
		d_{25} Range	d_{50} Range	d_{75} Range	Range	(%)	Range	Geom. Mean
Sand and Gravel	10	0.23-3.0	0.30-3.8	0.40-15	1-7	0	20-700	400
Sand Till	3	0.02-0.23	0.07-0.30	0.40-1.0	1-8	4-7	2- 40	20
Sand	9	0.01-0.05	0.03-0.13	0.10-0.24	1-2	1-6	5- 40	20

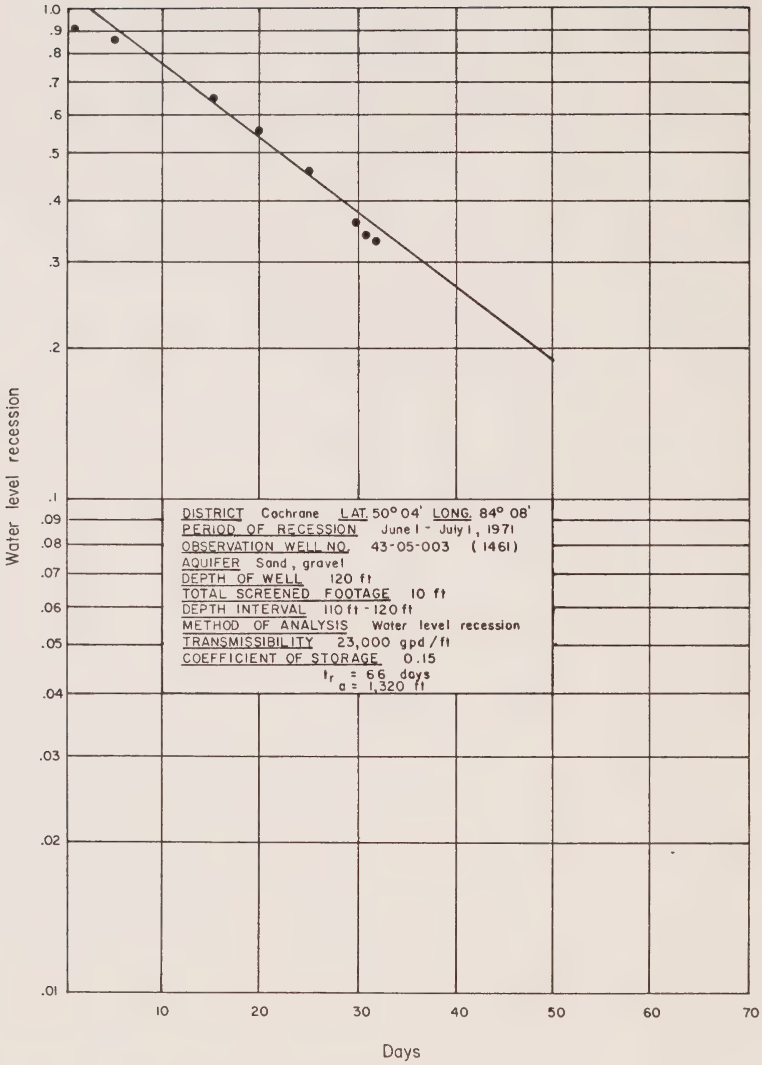


Figure 20. Water-level recession curve for observation well no. 43-05-003 in overburden, Albany River basin.

Attawapiskat River, Winisk River and Severn River Basins....

Grain-size distributions and permeabilities of aquifer materials in overburden were determined in the laboratory for 18 overburden samples collected from various parts of the Winisk River and Severn River basins (tables 12, 13). No samples were taken from the Attawapiskat River basin.

Mean permeabilities of sand samples in the Winisk and Severn River basins are about the same as those of sand tills (a little less than 1 gpd/ft^2). Mean permeabilities of sands and gravels in these basins are of the same order of magnitude as those found in the Moose River and the Albany River basins.

Water wells in the three basins are few and the available records are incomplete. Transmissibilities of overburden aquifers in the Attawapiskat and Severn River basins were determined from data of pumping tests conducted on two test holes (#575 and #659). The mean transmissibility for sand and sand till aquifers is 700 gpd/ft (Table 10) and the mean probable yield for individual wells is about 20 gpm.

AQUITARDS

Lignite/Clay

The lignite/clay unit occurs only in the southeastern part of the Lowland Region. Recovery data from a short-term pumping test on test hole #1657 was analysed using Jacob's (1950) formula and a transmissibility value of 50 gpd/ft was obtained.

Clays, Silts and Clay Tills

Laboratory determinations of particle sizes and permeabilities of these soil samples (tables 14, 15) indicated that these materials are of very low permeability and act as aquitards. Mean permeabilities are $2x10^{-2}$ gpd/ft^2 for clays and silts and $7x10^{-2}$ gpd/ft^2 for clay tills.

These aquitards play an important role in the regional movement of ground water. They retard the movement from shallow to deep aquifers and confine waters in deep aquifers.

The low transmissibilites of the aquitards limit the type and duration of hydraulic tests that can be carried out. Therefore, the hydraulic properties of aquitards were determined only from laboratory tests.

WATER-LEVEL FLUCTUATIONS AND CHANGES IN STORAGE

Annual water-level fluctuations in overburden and bedrock aquifers are the bases for estimating annual changes in ground-water storage.

The fluctuations of water levels were recorded in wells drilled for this study during the period 1968 to 1973. This network of drilled observation wells consisted of 36 overburden wells and 4 bedrock wells. Water levels of 12 wells were recorded by automatic recorders; the others were measured weekly or monthly by tape. Well

Table 12. Summary of Particle Size Distributions and Permeabilities of Aquifer Materials in Overburden, Winisk River Basin

Aquifer Material	Number of Samples	Particle Size (mm)			Sorting Coefficient	Clay Content	Permeability (gpd/ft^2)	
		d_{25} Range	d_{50} Range	d_{75} Range	$(d_{75}/d_{25})^{1/2}$ Range	(%)	Range	Geom. Mean
Sand and Gravel	2	0.03-0.1	0.15-0.20	0.7-0.9	2-4	0	-	400
Sand Till	5	0.01-0.1	0.02-0.8	0.5-4	2-6	0-4	7-100	50
Sand	1	0.04	0.08	0.12	2	4	-	40

Table 13. Summary of Particle Size Distributions and Permeabilities of Aquifer Materials in Overburden, Severn River Basin

Aquifer Material	Number of Samples	Particle Size (mm)			Sorting Coefficient	Clay Content	Permeability (gpd/ft^2)	
		d_{25} Range	d_{50} Range	d_{75} Range	$(d_{75}/d_{25})^{1/2}$ Range	(%)	Range	Geom. Mean
Sand and Gravel	7	0.20-0.70	0.60-5.7	0.80-15	1-5	0	2-400	100
Sand Till	2	0.20-0.50	0.40-0.90	0.90-20	2-3	0	-	20
Sand	1	0.02	0.03	0.07	3	11	-	40

Table 14. Summary of Particle Size Distributions and Permeabilities of Clays and Silts

Basin	Number of Samples	Particle Size (mm)			Sorting Coefficient $(d_{75}/d_{25})^{1/2}$	Permeability (gpd/ft^2)	
		d_{25} Range	d_{50} Range	d_{75} Range	Range	Range	Geom. Mean
Moose	5	0.004-0.05	0.007-0.2	0.01-0.4	2-5	$4x10^{-3}$ - $9x10^{-3}$	$5x10^{-3}$
Albany	2	0.004	0.01-0.02	0.03-0.07	3-5	-	$4x10^{-3}$
Winisk	2	0.009-0.1	0.03-0.2	0.07-0.3	2-3	-	$4x10^{-2}$
Severn	5	0.004-0.04	0.01-0.04	0.06-0.7	2-4	$7x10^{-3}$ - $9x10^{-2}$	$4x10^{-2}$
All Basins	14	0.004-0.01	0.007-0.2	0.01-0.7	2-5	$4x10^{-3}$ - $9x10^{-2}$	$2x10^{-2}$

Table 15. Summary of Particle Size Distributions and Permeabilities of Clay Tills

Basin	Physiographic Region	Number of Samples	Particle Size (mm) d_{25} Range	d_{50} Range	d_{75} Range	Sorting Coefficient $(d_{75}/d_{25})^{1/2}$ Range	Permeability (gpd/ft^2) Range	Geom. Mean
Moose	Shield	4	0.005-0.01	0.020-0.06	0.08-0.2	3-5	$2x10^{-3}$ - $4x10^{-1}$	$1x10^{-1}$
	Lowland	7	0.005-0.05	0.01-0.1	0.03-1	1-7	$2x10^{-3}$ - $5x10^{-1}$	$9x10^{-2}$
Albany	Shield	4	0.007-0.04	0.03-0.07	0.1-1	3-11	$2x10^{-3}$ - $5x10^{-2}$	$2x10^{-2}$
	Lowland	19	0.005-0.04	0.002-0.2	0.03-0.7	1-8	$9x10^{-4}$ - $5x10^{-2}$	$7x10^{-3}$
Severn	Shield	2	0.004-0.008	0.01-0.03	0.07-0.08	3-4	-	$4x10^{-1}$
	Lowland	1	0.04	0.06	0.1	2	-	$5x10^{-3}$
Winisk	Shield	2	0.007-0.05	0.025-0.03	0.1-0.15	2-5	-	$7x10^{-2}$
All Basins	Shield	12	0.004-0.05	0.01-0.07	0.08-1	2-11	$2x10^{-3}$ - $5x10^{-2}$	$2x10^{-2}$
	Lowland	27	0.005-0.05	0.01-0.2	0.03-1	1-8	$9x10^{-4}$ - $5x10^{-1}$	$4x10^{-2}$
	Total	39	0.004-0.05	0.01-0.02	0.03-1	1-11	$9x10^{-4}$ - $5x10^{-1}$	$7x10^{-2}$

logs and water-level data of the observation wells have been published in Water Resources bulletins 1-1 through 1-5; locations are shown on Map 6 and a brief history of each observation well is summarized in Appendix C.

Comparisons of water levels are made for wells at different depths and between wells and rivers. Depths to water levels from ground surface influence significantly the patterns and magnitudes of water-level fluctuations. Water levels at shallow depth, in general, rise more rapidly in response to precipitation and fluctuate in greater amplitude than water levels at great depths. Water levels in wells are generally higher than in rivers indicating that rivers are generally effluent.

In Crystalline Rocks

Fluctuations of piezometric surfaces in crystalline rock in the Muskrat Dam Lake area, Severn River basin, were recorded by observation well #47-05-001R (Figure 21). The well is 92 feet deep and ends in fractured schist. An automatic recorder was installed and has recorded water levels continuously since mid 1970.

Both the ground-water stage in this well and the river stage at streamflow gauging station 04CA002 decline in the winter and early spring months and rise in response to recharge from snowmelt in middle spring. However, river stage rises rapidly to an annual peak level in late May and declines after the spring melt with little rise in the autumn. The ground-water stage rises gradually in the spring and reaches an annual peak in late fall.

In Sedimentary Rocks

Water-level fluctuations in limestone/dolomite in the Hat Island area, Albany River basin, were recorded by observation well #43-05-004R (Figure 22). The well is 150 feet deep and an automatic recorder was installed in 1970.

Water-level fluctuations in this well are generally similar to water-level fluctuations at streamflow gauging station 04HA001 on the Albany River. The main differences are the relatively greater fluctuations of the river stage than that of ground water and the lag time between the occurrences of peaks and troughs. During the period of observation, water levels in the observation well were constantly more than 20 feet above the river stage indicating that ground water in the limestone/dolomite was discharging into the Albany River.

In Overburden

Water-level fluctuations in overburden are compared for three situations: between an unconfined and a confined aquifer, between a shallow and a deep aquifer, and between an overburden aquifer and a river.

Hydrographs for two observation wells (#43-05-014-1 and #43-05-014-3) in an unconfined aquifer and observation well (#43-05-014-4) in a confined aquifer in the Nakina area in the Albany River basin, have essentially the same shape (Figure 23). Water levels in the unconfined aquifer, however, show somewhat smaller fluctuations and were generally 5 feet higher during 1972 and 1973 than levels in the confined aquifer.

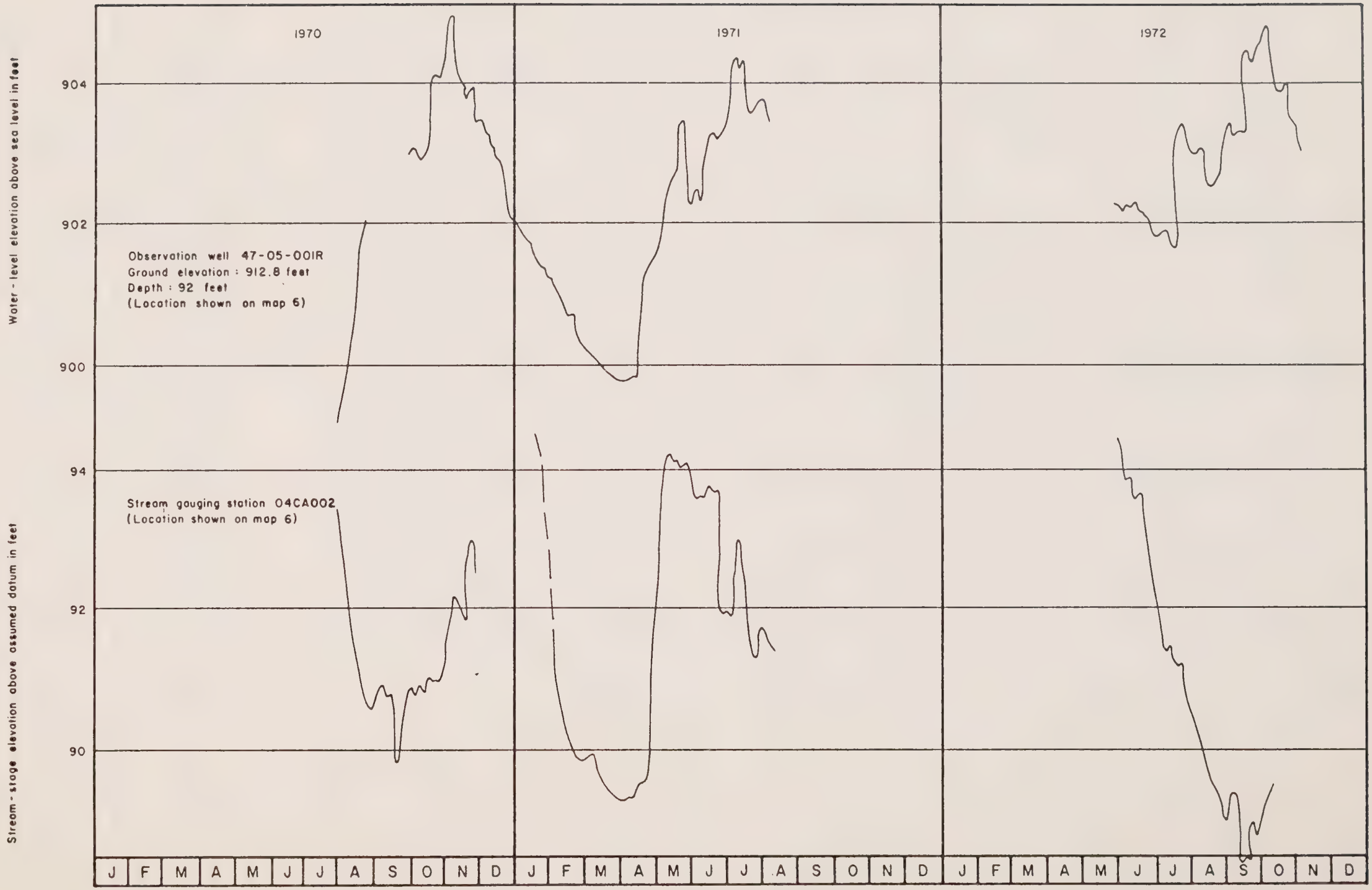


Figure 2l. Hydrographs for observation well 47-05-00IR in crystalline rock and stream-stage elevation for gauging station O4CAOO2, Muskrat Dam Lake, Severn River basin.

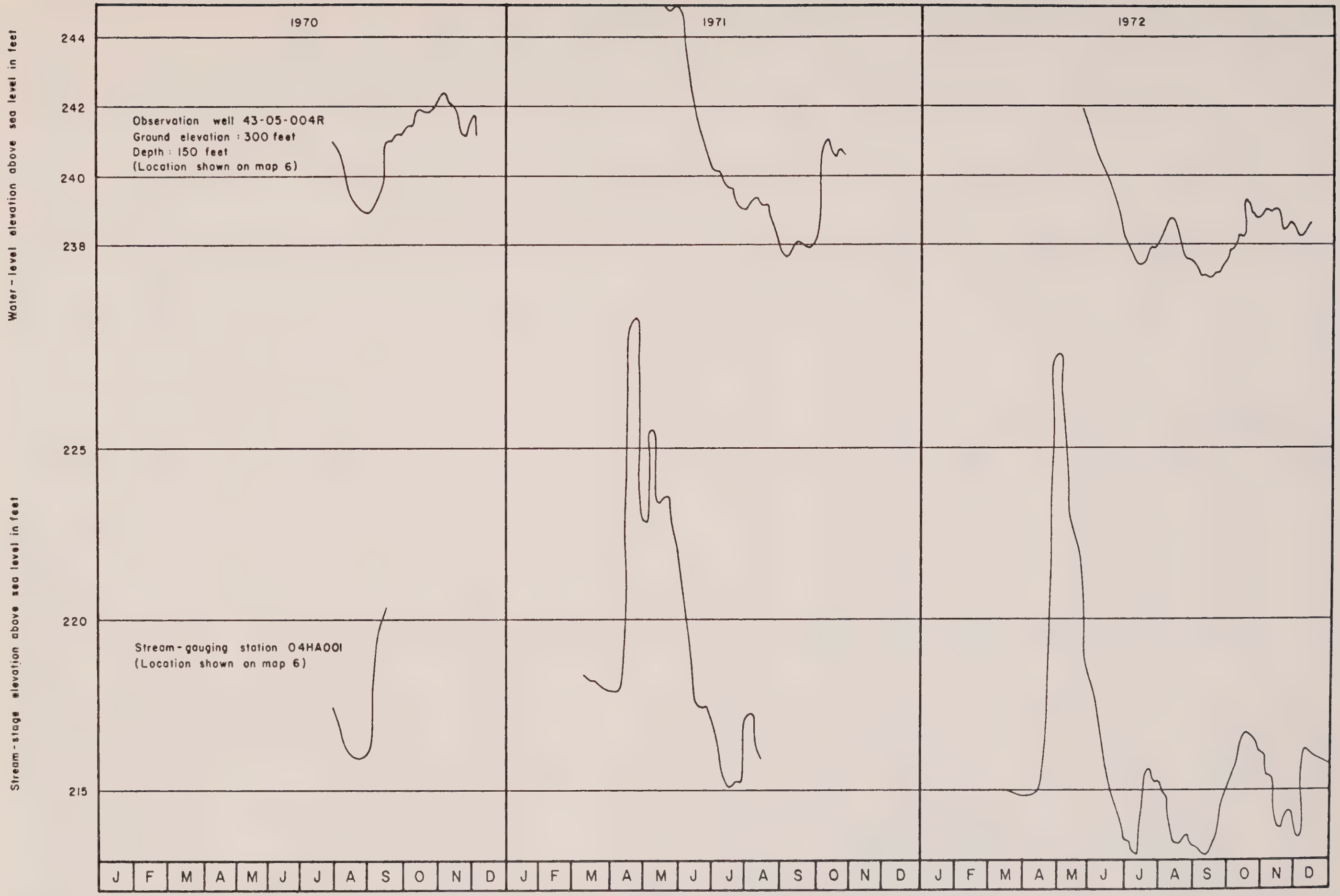


Figure 22. Hydrographs for observation well 43-05-004R in a limestone / dolomite aquifer and stream-stage elevation for gauging station 04HA001, Hat Island, Albany River basin.

Observation well	Ground elevation in feet	Depth of well in feet	Aquifer material	Average depth to water in feet	Type of measurment
43-05-014-1	1112	27	sand gravel	10.5	manual
43-05-014-3	1112	46	sand gravel	11.0	manual
43-05-014-4	1112	93.5	sand till	16.0	manual

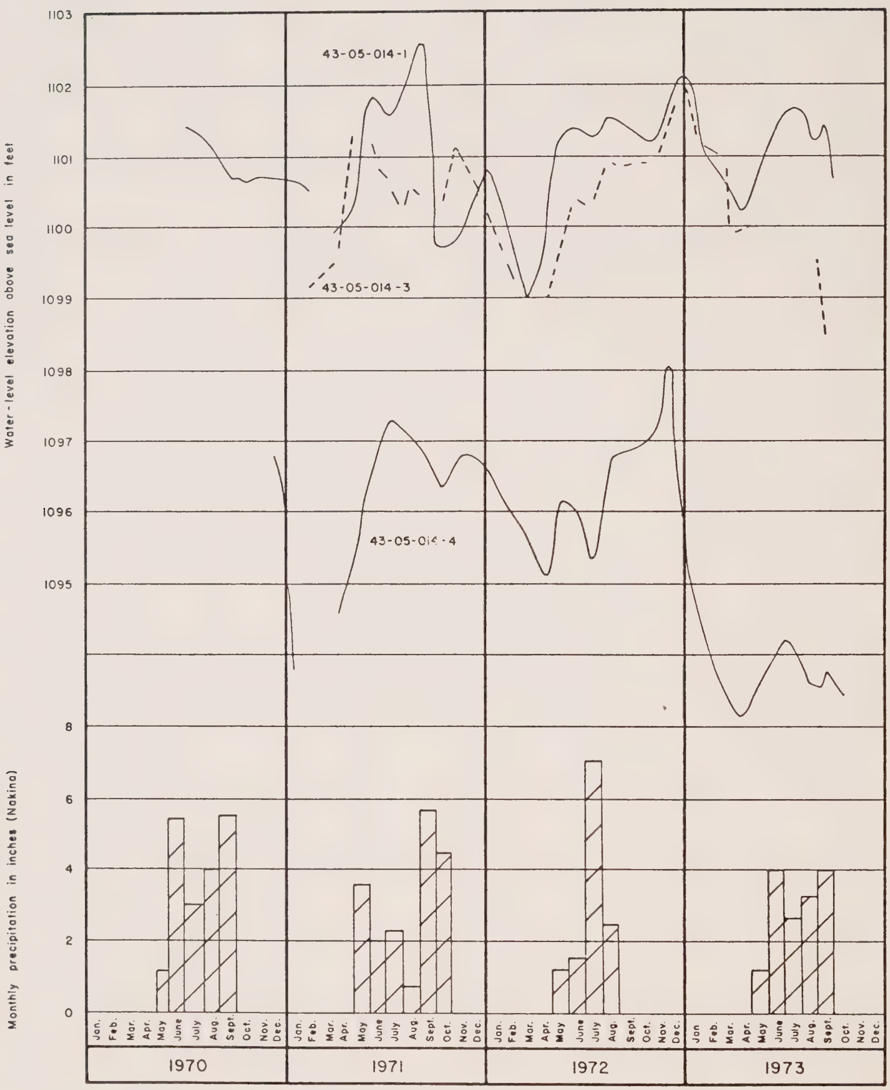


Figure 23. Monthly precipitation and water-level hydrographs for three observation wells in overburden, Nakina, Albany River basin.

Hydrographs for a shallow well (#44-05-007-2R) and a deep well (#44-05-005R) show typical water-level fluctuations in overburden in the Pickle Lake area, Attawapiskat River basin (Figure 24). The water level in the shallow well shows larger fluctuations than that in the deep well. The level in the shallow well fluctuated about 4 to 5 feet during 1972 and 1973, whereas the water level in the deep well fluctuated less than a foot during the same period.

Water-level in observation well #44-05-001R in overburden shows generally similar fluctuations as water-level at streamflow gauging station 04FA001 on the Attawapiskat River (Figure 25). The main difference is the relatively greater magnitude and the greater number of minor fluctuations in the river stage than those in the ground-water stage. For the period 1972 to 1973, water levels in the well were generally 10 feet above the river stage.

Change in Ground-Water Storage

The annual change in ground-water storage is the volume of water that drains from a saturated formation when the level declines from its annual high to its annual low position. This volume was calculated from the product of the area of the aquifer, the average annual fluctuation of water level, the specific yield for overburden aquifers, all of which were assumed to be unconfined, or the coefficient of storage for bedrock aquifers which were assumed to be confined.

For the calculation, a specific yield of 0.15 was assumed for the unconfined overburden aquifers and coefficients of storage of 5 x 10^{-5} and 5 x 10^{-4} were assumed for the confined crystalline and sedimentary rocks, respectively.

Estimated annual change in storage from 1970 to 1972 for all aquifers is 4366 billion gallons (Table 16); of which less than 0.5% or 16 billion gallons occur in bedrock aquifers.

MOVEMENT, DISCHARGE AND RECHARGE OF GROUND WATER

Ground water moves from places of recharge to places of discharge. The rate of movement ranges from a few feet to a few hundred feet per year. Brine in the deep zones of the sedimentary basins in the Lowland Region is probably indicative of slow movement.

Recharge to an aquifer is often used as an indicator of the amount of ground water available for development. The main source of recharge to overburden aquifers is by infiltration of precipitation and snowmelt in areas of high permeability (sands and gravels). Recharge to bedrock aquifers occurs in areas of outcrop or subcrop underlying the overburden.

Movement of Ground Water

Ground water often moves along intricate and complex paths. This complex movement is governed by two major components of hydraulic gradient: the vertical and horizontal components.

The vertical component of gradient causes ground water to move upwards or downwards from one hydrogeologic unit to another, depending on the hydraulic head difference between the upper and the lower units. In a large part of the Shield Region and on the high

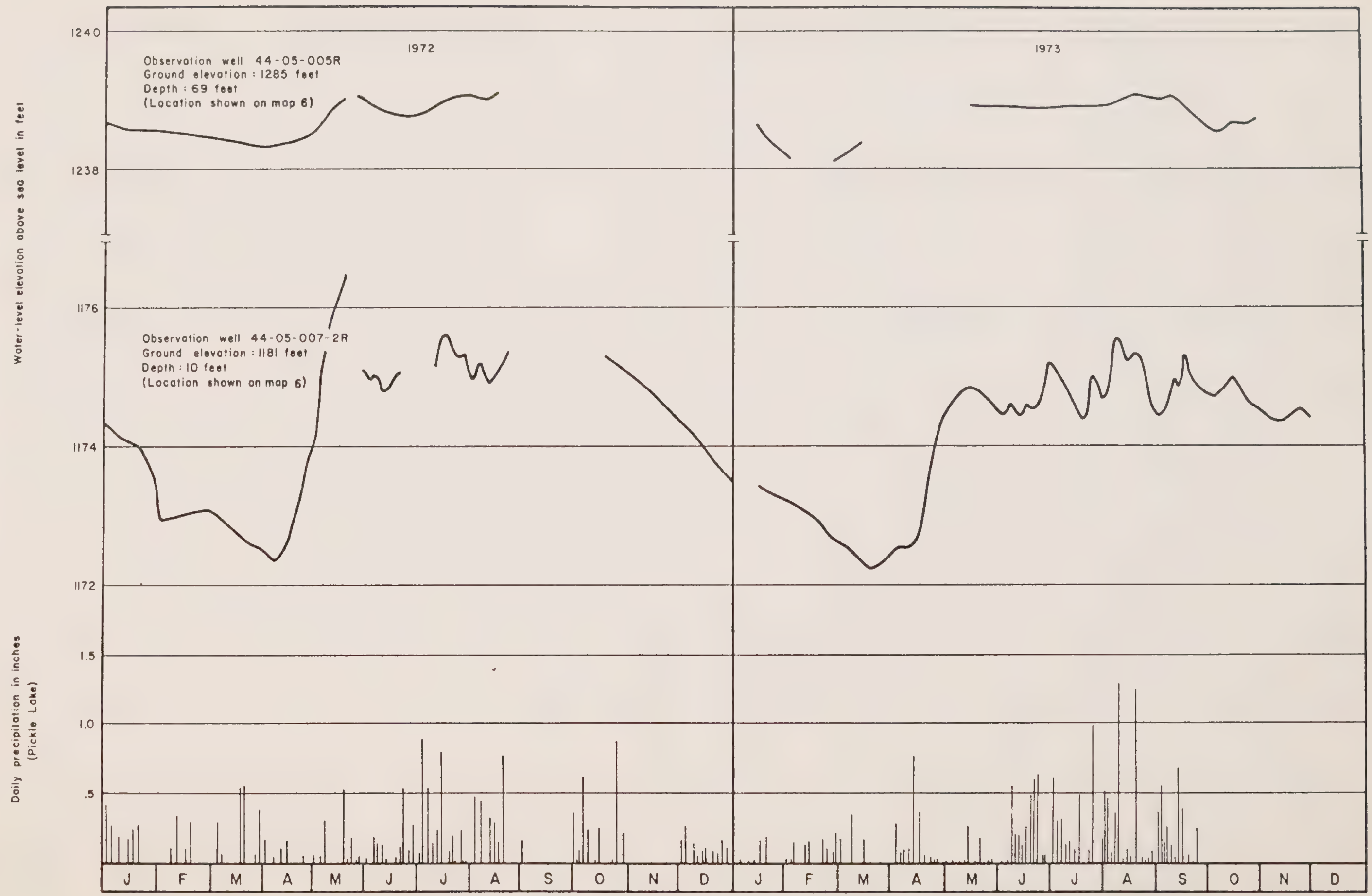


Figure 24. Daily precipitation and water-level hydrographs for two observation wells in overburden, Pickle Lake, Attawapiskat River basin.

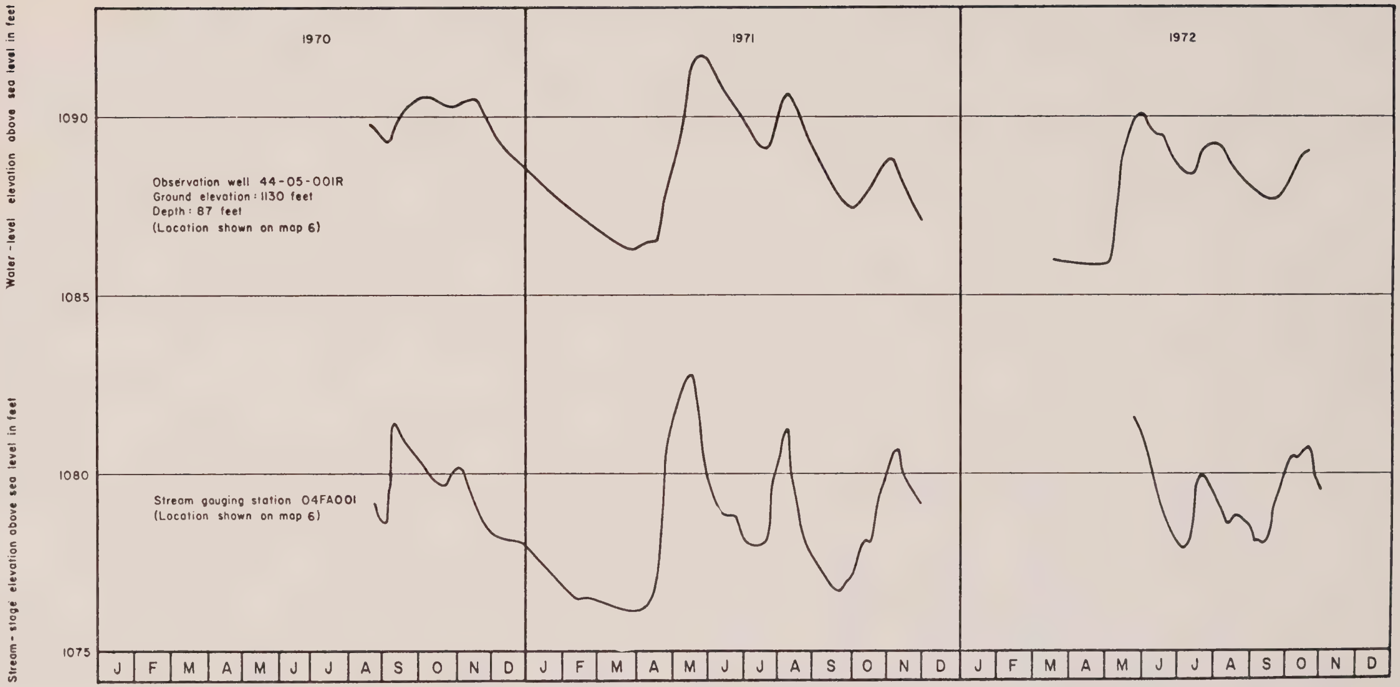


Figure 25. Hydrographs for observation well 44-05-001R in overburden and stream-stage elevation for gauging station 04FA001, Badesdawa Lake, Attawapiskat River basin.

Table 16. Annual Changes In Ground-Water Storage, 1970-72

Aquifer	Specific Yield or Coefficient of Storage	Average Annual Range of Fluctuation (ft)	Moose Area (mi^2)	Moose ΔS (bg)	Albany Area (mi^2)	Albany ΔS (bg)	Attawapiskat Area (mi^2)	Attawapiskat ΔS (bg)	Winisk Area (mi^2)	Winisk ΔS (bg)	Severn Area (mi^2)	Severn ΔS (bg)	Total Area (mi^2)	Total ΔS (bg)
Overburden	0.15	2.5	25600	1670	12000	782	7660	499	11500	749	9980	650	66740	4350
Bedrock Crystalline	$5x10^{-5}$	4	13000	0.5	22900	0.8	3300	0.1	4470	0.2	13100	0.5	56770	2.1
Limestone/ Dolomite	$5x10^{-4}$	3	3300	0.9	12900	3.4	7480	1.9	8630	2.2	12600	3.3	44910	11.7
Sandstone/ Limestone	$5x10^{-4}$	3	-	-	910	0.2	890	0.2	1610	0.4	1280	0.3	4690	1.1
Sandstone/ Siltstone	$5x10^{-4}$	3	-	-	2920	0.8	-	-	-	-	680	0.2	3600	1.0
Total			41900	1671	51630	787	19330	501	26210	752	37640	654	176710	4366*

* No data are available for limestone and carbonaceous shale. The annual changes in ground-water storage for aquifers in these rocks (not included in this total) are estimated to be negligible in comparison to this total because of the relatively small areal extent of these rocks.

ground in the Lowland Region, ground water in surficial units moves downward into underlying deep units. Ground water in the deep aquifers under river valleys in the Lowland Region often has a higher hydraulic head than in the surficial deposits and therefore moves upward towards the surficial units.

The horizontal component of hydraulic gradient causes ground water to move laterally. The lateral movement in the shallow systems is usually towards local discharge points such as lakes and streams. This type of movement is predominant in the Shield Region. The lateral movement in the deep systems that are in bedrock in the Lowland Region is towards Hudson Bay and James Bay.

Evidence of Vertical Movement.... Downward movement of ground water from one hydrogeologic unit to another is illustrated by overburden aquifers in the Nakina area, Albany River basin. Hydrogeologic units consist of a sand and gravel aquifer overlying a clay aquitard which in turn overlies a sand till aquifer.

Average static water-levels for observation wells #43-05-014-1 and #43-05-014-3 in the upper aquifer are 10.5 and 11 feet below ground surface whereas the average level for well #43-05-014-4 in the lower aquifer is 16.0 feet below ground surface (Figure 23). The higher head in the upper aquifer causes water to move downward to recharge the lower aquifer.

Upward movement from a lower to an upper aquifer in a stream valley was evidenced by data from observation wells #43-05-017-1 and #43-05-017-2 in the Nakina area. Water levels rose to 1 foot above ground surface at 15 feet and to 1.4 feet above ground surface at a depth of 30 feet. Since the hydraulic head in the deeper aquifer is greater than that in the shallow aquifer, ground water moves upwards in the area.

Upward movement of ground water was also evidenced in Paleozoic aquifers in river valleys of the Lowland Region. During test drilling in well #630 at the Hat Island site, static hydraulic pressure of the ground water was 2 psi at a depth of 67 feet and 18 psi at a depth of 94 feet. This higher pressure at greater depth causes an upward movement of ground-water.

Evidence of Lateral Movement.... Cross-sections based on water-well data indicate that the water-table configuration is generally a subdued replica of ground surface topography. It is assumed, therefore, that surface topographic trends can be used to interpret the general directions of shallow ground-water movement. Based on surface topography, ground water in shallow aquifers in the Shield Region moves locally towards streams and lakes.

Water-level elevations in wells penetrating carbonate aquifers in the Lowland Region indicate a very low lateral gradient from the Precambrian-Paleozoic contact towards Hudson Bay. The elevations of water levels in wells #657 and #635 differ by 92 feet; the distance between the wells is approximately 28 miles, which indicates a hydraulic gradient of 3.2 feet per mile towards Hudson Bay. In a 20-mile distance between wells #1705 and #1706, the difference in water-level elevations is 56 feet, which indicates an average hydraulic gradient of 2.8 feet per mile toward Hudson Bay and James Bay. The lateral movement of ground water in the carbonate aquifers is interrupted by an aquitard of Precambrian rock (Cape Henrietta Maria Arch).

Discharge of Ground Water

Assuming no significant changes in ground-water storage, the annual discharge of ground water is the basis for estimating annual recharge by precipitation to aquifers in the area. The principal discharges from aquifers are from the lateral movement of ground water in two main directions. These are:

a. localized movement to streams that eventually discharge into Hudson Bay and James Bay;
b. movement towards and discharge along the coastline into Hudson Bay and James Bay.

Withdrawals (discharges by pumping) from aquifers are insignificant in comparison to these discharges.

Ground-water discharges to streams were estimated from streamflow data because ample hydrogeologic data were not available. Discharges to Hudson Bay and James Bay were estimated from hydrogeologic considerations.

Discharge to Streams.... According to Wyrick and Lloyd (1968), the ground-water component of streamflow may be estimated from the stream discharge which may vary between the daily stream discharge exceeded 60% and 90% of the time. In the present study, the daily stream discharge exceeded 90% of the time is used as a measure of ground-water discharge to streams. This lower value is used for two reasons:

a. large amounts of precipitation are stored as snow and frost because of the cold climate;
b. large quantities of water from direct runoff are stored in the numerous lakes.

The five major basins were first sub-divided into 45 sub-basins (Map 6). Daily flow-duration curves for the period 1968 to 1974 were produced from data published by the Water Survey of Canada for each streamflow gauging station shown on the map. Ground-water discharge from a sub-basin at the head water areas was obtained directly from the 90% flow-duration data. The discharge from a sub-basin in a downstream area was obtained by subtracting the sum of upstream discharges from the discharge at the downstream station. Where large reservoirs control flows, the flows downstream of the reservoirs were not suitable for estimating ground-water discharges. The 90% exceedances at these sites were determined from average values of streamflows for non-regulated tributaries.

Average annual ground-water discharge to rivers in the five major basins during the period 1968 to 1974 is estimated to be 6800 billion gallons per year (Table 17). The largest amount comes from the Moose River basin (34%) and the smallest from the Attawapiskat River basin (8%). Results for each of the 45 sub-basins shown on Map 6 are deferred for discussion under the section "Recharge to Ground Water".

Table 17. Estimates of Annual Ground-Water Discharges to Rivers in the Five Major Basins, 1968-1974

Basin	Area mi^2	Yield cfs/mi^2	Discharge cfs	Annual Discharge billion gallons/year	Percent of Total Annual Discharge
Moose	41,900	0.28	11,700	2,300	34
Albany	51,700	0.18	9,300	1,800	27
Attawapiskat	19,300	0.15	2,900	600	8
Winisk	26,200	0.16	4,200	800	12
Severn	37,600	0.18	6,800	1,300	19
All Basins	176,700	0.20	34,900	6,800	100

Table 18. Estimates of Ground-Water Recharge

Basin	Sub-Basin	Area (mi^2)	90% Flow (Rg) (cfs/mi^2)	(inches)	Precipitation (PP) (inches)	Rg/PP %
Moose	1. Black	5130	0.57	7.7	33	24
	2. U. Abitibi	2880	0.55	7.5	32	24
	3. U. Mattagami	2370	0.54	7.3	31	24
	4. M. Mattagami	1490	0.43	5.8	31	19
	5. Groundhog	4610	0.36	4.9	29	17
	6. Kapuskasing	2610	0.24	3.3	29	11
	7. U. Missinaibi	3450	0.16	2.2	29	7
	8. L. Abitibi	2590	0.24	3.3	31	10
	9. L. Mattagami	2320	0.22	3.0	30	10
	10. L. Missinaibi	6750	0.15	2.0	29	7
	11. N. French	2580	0.13	1.8	31	6
	12. L. Moose	3520	0.03	0.4	30	1
	13. Kwataboahegan	1640	0.03	0.4	29	1
Subtotal	Moose Basin	41940				
Average	Moose Basin		0.28	3.8	30	13
Albany	1. Kabinakagami	1460	0.30	4.1	29	14
	2. Shekak	1270	0.24	3.3	29	11
	3. Nagagami	930	0.46	6.2	29	21
	4. Long Lake	1650	0.24	3.3	28	12
	5. Kapikotongwa	2070	0.28	3.8	28	13
	6. Ogoki	5260	0.24	3.3	29	11
	7. Lake St. Joseph	4210	0.24	3.3	27	12
	8. Cat Lake	2080	0.44	6.0	25	24
	9. U. Albany	6210	0.30	4.1	28	14
	10. M. Albany	15470	0.10	1.4	28	5
	11. Kenogami	6500	0.10	1.4	29	4
	12. L. Albany	6290	0.03	0.4	27	2
Subtotal	Albany Basin	51690				
Average	Albany Basin		0.18	2.5	29	9
Attawapiskat	1. Otoskwin	3480	0.23	3.1	29	12
	2. Pineimuta	1890	0.17	2.3	25	9
	3. U. Attawapiskat	3960	0.26	3.5	25	14
	4. M. Attawapiskat	4570	0.12	1.6	26	5
	5. L. Attawapiskat	5430	0.03	0.4	25	2
Subtotal	Attawapiskat Basin	19330				
Average	Attawapiskat Basin		0.15	2.1	25	8
Winisk	1. Pipestone	2300	0.20	2.7	24	11
	2. U. Winisk	5040	0.31	4.2	25	17
	3 U. Asheweig	1250	0.19	2.6	24	11
	4. L. Asheweig	1820	0.22	3.0	24	12
	5. M. Winisk	8890	0.13	1.8	24	8
	6. Shamattawa	1820	0.06	0.8	24	3
	7. L. Winisk	5040	0.03	0.4	23	2
Subtotal	Winisk Basin	26160				
Average	Winisk Basin		0.16	2.2	24	9
Severn	1. Windigo	4160	0.45	6.1	24	26
	2. Deer Lake	1780	0.31	4.2	19	22
	3. U. Severn	8400	0.23	3.1	20	16
	4. U. Sachigo	1650	0.34	4.6	20	23
	5. Big Trout Lake	1680	0.45	6.1	23	26
	6. M. Severn	12460	0.06	0.8	21	4
	7. L. Sachigo	6510	0.09	1.2	20	6
	8. L. Severn	1000	0.03	0.4	20	2
Subtotal	Severn Basin	37640				
Average	Severn Basin		0.18	2.5	21	12
Total	All Basins	176760				
Average	All Basins		0.20	2.7	26	10

Abbreviations: U - Upper, M - Middle, L - Lower, N - North

Discharge to Hudson Bay and James Bay.... The discharge (Q) of ground water to Hudson Bay and James Bay is estimated from the product of hydraulic gradient (i), average transmissibility (T) and the total length of coastal line (L) perpendicular to the flow i.e.,

$$Q = TiL$$

Hydraulic gradient in the coastal area is approximately 2.5 feet/mile and the transmissibility of the limestone/dolomite aquifer along the coast averages about 12,000 gpd/ft. The discharge of ground water to Hudson Bay and James Bay along the 600 mile coastal line is thereby estimated to be 18 mgd or 9.4 billion gallons per year.

Recharge to Ground Water

The average annual recharge to ground water is often assumed to be the maximum limit of ground water available perenially. Under long-term hydrologic conditions, ground water leaving (discharging) an aquifer system can be used to approximate the ground water entering (recharging) the system. Annual ground-water withdrawals by pumping (0.007 billion gallons) and annual discharges to Hudson Bay and James Bay (9.4 billion gallons) are insignificant in comparison to the annual ground-water discharge to streams in the five major river basins (6800 billion gallons). Ground-water discharges to streams, therefore, are used to approximate the amount of water recharged to aquifers.

Estimated annual ground-water recharge for each of the 45 sub-basins shown in Map 6 are given in Table 18. In general, ground-water recharge is highest in the southern part of the Shield Region and lowest in the Hudson Bay Lowland Region. Annual recharge, as a percentage of annual precipitation, is highest in the Moose River basin (13%) and lowest in the Attawapiskat River basin (8%).

Moose River Basin.... Of the five river basins, ground-water recharge in the Moose River basin is highest. Average recharge is 3.8 inches or 13% of the annual precipitation. Highest recharge in this basin occurs in the southeastern parts. The four sub-basins (Black, upper Abitibi, upper and middle Mattagami) which occupy about 40% of the drainage area receive about 65% of the total basin recharge. Recharge is highest (7.8 inches) in the Black sub-basin and lowest (0.4 inches) in the Kwataboahegan and lower Moose sub-basins.

Albany River Basin.... Ground-water recharge in the Albany River basin is highest in sub-basins at the southern periphery of this watershed. These sub-basins occupy about 50% of the total basin area but receive about 75% of the total basin recharge. Recharge is highest (6.2 inches) in the Nagagami sub-basin and lowest (0.4 inches) in the lower Albany sub-basin. Recharge in the Albany basin averages 2.5 inches, or 9% of the annual precipitation.

Attawapiskat River Basin.... Average recharge to ground water in the Attawapiskat River basin is the lowest among the five basins. Average recharge is 2.1 inches or 8% of annual precipitation. The southern parts of the basin are most favourable for ground-water recharge where the three sub-basins of Otoskwin, Pineimuta and upper Attawapiskat occupy 48% of the total area but receive 72% of the total recharge. The highest recharge (3.5 inches) occurs in the upper Attawapiskat sub-basin and the lowest (0.4 inches) in the lower Attawapiskat sub-basin.

Winisk River Basin.... Highest ground-water recharge in the Winisk River basin occurs in four sub-basins (Pipestone, upper Winisk, upper and lower Asheweig) in the upper part of the basin. These sub-basins occupy 40% of the total basin area and receive 64% of the total recharge. Recharge varies from 4.2 inches or 17% of precipitation for the upper Winisk sub-basins to 0.40 inches or 2% of precipitation for the lower Winisk. Average recharge for the Winisk basin is 2.2 inches or 9% of annual precipitation.

Severn River Basin.... Average recharge in the Severn River basin is the second highest among the five major basins. Average recharge is 2.5 inches or 12% of annual precipitation. The major recharge areas are the morainic ridges that bound the Shield Region. The five sub-basins of Deer Lake, Windigo, upper Severn, Big Trout Lake, and upper Sachigo, occupy 48% of the total Severn River basin area and receive 80% of the total basin recharge. Highest recharge (6.1 inches) occurs in the Windigo and Big Trout Lake sub-basins. Recharge is lowest (0.4 inches) in the lower Severn sub-basin.

WATER QUALITY

INTRODUCTION

Ground-water quality in northern Ontario is indicated by general inorganic chemical analyses of water samples taken from 209 selected wells and springs. These samples were collected during the field season from 1968 to 1972. Results of the analyses have been published in OWRC and MOE Water Resources bulletins 1-1 through 1-5. Sample locations and pertinent data are shown on Map 5.

Recommended permissible criteria for some common inorganic constituents in public water supplies are as follows:

chloride	= 250 mg/l
iron	= 0.3 mg/l
nitrate (as N)	= 10 mg/l
sulphate	= 250 mg/l
total dissolved solids	= 500 mg/l

These constituents, while not reflecting the toxicity of waters, should not exceed the above concentrations where other suitable supplies are or can be made available.

For ease of discussion, the hardness of water in this report is classified as follows:

Total Hardness (mg/l as Ca CO_3)	Classification
less than 60	soft
61-120	moderately hard
121-180	hard
greater than 180	very hard

Ground waters in northern Ontario are generally hard to very hard. With the exception of iron, the inorganic constituents listed above are generally lower than the permissible criteria for public supplies. Iron often exceeds the permissible criteria of 0.3 mg/l; however, this criteria relates primarily to objectionable tastes, aesthetics and problems caused by iron precipitates, and waters containing more than 0.3 mg/l iron can still be considered for use for public supplies.

Waters from overburden and crystalline rocks are less mineralized than those obtained from sedimentary rocks (Table 19). Waters from overburden and crystalline rocks are predominantly of calcium-bicarbonate type. Waters from sedimentary rocks vary from a calcium-bicarbonate type in an area near the Precambrian-Paleozoic contact to a sodium-chloride type in the coastal area. The relative abundance of the major anions and cations in ground water is illustrated by representative samples in diagrams shown in Appendix D.

Table 19. Concentrations of Common Chemical Constituents in Ground-Water Samples

Chemical Constituents	Concentration mg/1								
	Overburden			Crystalline Rocks			Sedimentary Rocks		
	Maximum	Minimum	Median	Maximum	Minimum	Median	Maximum	Minimum	Median
Na	135	1	8	80	2	13	1280	135	262
K	15	<0.1	6	103	0.7	3	401	3	5
Ca	197	11	82	314	40	93	250	53	86
Mg	92	1	14	88	3	17	160	22	38
Cl	207	1	3	53	1	3	2310	2	312
SO_4	270	<1	7	970	<1	10	560	3	23
NO_3 (as N)	5.3	<0.01	0.15	5.5	<0.01	<0.01	1.1	<0.01	0.01
Fe	221	0.05	0.7	10	<0.05	1.0	7	0.03	0.33
Hardness (as $CaCO_3$)	660	34	292	1152	40	290	1185	195	335
TDS	1185	40	360	1970	40	400	4700	600	1120

136 samples from wells in overburden
53 samples from wells in crystalline rocks
20 samples from wells in sedimentary rocks

IN CRYSTALLINE ROCKS

The chemical quality of water in crystalline rocks was determined from 53 samples from bedrock wells. Twenty-five samples were obtained from the Moose River basin and 19 from the Albany River basin. Only 9 samples were obtained from the Attawapiskat, Winisk and Severn river basins because only few wells exist in these areas.

Waters from crystalline rocks are commonly of a calcium-bicarbonate type. Magnesium-ion concentrations are generally greater than sodium, and the waters are very hard. Concentrations of common inorganic constituents are generally lower than the permissible criteria for public water supplies. Iron, however, exceeds the criterion (0.3 mg/l) in most samples.

Median concentrations of total dissolved solids and sulphates are 400 mg/l and 10 mg/l, respectively. Total dissolved solids and sulphate in sample #43-07-08 obtained from a well near Geraldton are 1970 mg/l and 1152 mg/l, respectively. These high concentrations are atypical of waters from crystalline rocks; however, the reason for the high values is not known.

IN SEDIMENTARY ROCKS

Moose River Basin

Few wells penetrate into sedimentary rocks in the Moose River basin. Fresh water was found in well #1362 near the Moose River Crossing while salt water was found in well #468 at the Moose Factory Hospital and in four test holes in Moosonee.

Only five water samples were obtained from limestone/dolomite in the Moosonee area. All are of a sodium-chloride type. Total dissolved solids concentrations average more than 4000 mg/l and concentrations of all the common inorganic chemical constituents are far in excess of the permissible criteria for public supplies. These waters are generally not suitable for domestic use.

Albany River Basin

Fourteen samples were obtained from test holes in sedimentary rocks at seven sites in the Albany River basin. Five samples are of a calcium-bicarbonate type, seven of a sodium-bicarbonate type and two of a sodium-chloride type.

Calcium-bicarbonate and sodium-bicarbonate type waters are very hard and contain iron and total dissolved solids in some wells in excess of the permissible criteria for public supplies. However, the waters are considered generally suitable for domestic use.

Sodium-chloride type waters contain total dissolved solids ranging between 800 and 2760 mg/l and most of the common inorganic constituents exceed the permissible criteria. These waters are generally not suitable for domestic use.

Waters in sedimentary rocks in the basin contain much more dissolved solids than waters from overburden or crystalline rocks. Total dissolved solids in sedimentary rocks range from 400 mg/l to 2760 mg/l with a median of 1100 mg/l. There is generally an

increase in dissolved solids towards coastal areas in the basin. Chloride concentration, for example, increases from less than 50 mg/l in an area east of Hat Island (120 miles inland) on the Albany River to more than 800 mg/l in the Big Island area near Fort Albany, about 30 miles east of the coastal shoreline. Chloride concentrations at depths of more than 1000 feet are very high. A concentration of more than 19,000 mg/l was reported from a well 1400 feet below the bedrock surface at Puskwuche Point (Satterly, 1953).

IN OVERBURDEN

Moose River Basin

Water quality information in overburden aquifers in the Moose River basin was obtained from 77 samples collected from various parts of the basin. Calcium-bicarbonate type waters are common; magnesium and sodium ions are also abundant but chloride and sulphate are less abundant. With the exception of iron, the concentrations of the common inorganic constituents are generally lower than the permissible criteria for public supplies.

The waters are very hard and the total dissolved solids concentrations are generally less than 700 mg/l with a median of 400 mg/l.

The waters from two dug wells (#42-07-30 and #42-07-31) with chloride concentrations exceeding 100 mg/l may be contaminated.

Albany River Basin

Analyses of 43 water samples from overburden wells and springs in the Albany River basin indicate that the waters are predominantly a calcium-bicarbonate type. Magnesium-ion concentrations are generally greater than sodium and most waters are very hard. With the exception of iron, most common chemical constituents are lower than the permissible criteria for public supplies.

Waters in overburden in the Albany River basin are less mineralized than those in the Moose River basin. Total dissolved solids range from 44 to 790 mg/l with a median of 240 mg/l.

Water from a dug well (#43-07-36) has the highest chloride concentration (209 mg/l) and may be contaminated.

Attawapiskat River, Winisk River and Severn River Basins

There are few water wells in these basins and only sixteen water samples were taken from overburden wells; twelve were from test holes and four were from water wells in Central Patricia. Calcium-bicarbonate type waters are common with sulphate ions generally more abundant than chloride. Waters are hard and only iron exceeds consistently the permissible criteria for public supplies.

Total dissolved solids range from 40 to 835 mg/l with a median of 145 mg/l. The spread of mine tailings on the ground in the eastern part of the municipality of Central Patricia may account for the high total dissolved solids content (835 mg/l) in sample #44-07-07.

WATER USE

GROUND-WATER USES

There is generally very little data available regarding ground-water uses in the northern Ontario study area. As a result, the quantity and uses of ground water have been deduced from information contained within water-well records on file with the MOE. Actual withdrawals from each well have not been recorded; however, the test rates for these wells at the time of their completion have been reported. Assuming that test rates reflect the user's eventual needs, then ground-water withdrawals can be estimated and are assumed to be 50 percent of the test rates.

Up to the end of 1972 there were 1756 wells (about 84 percent of all wells in the area) with available information. Total ground-water withdrawals in 1972 were estimated to be 7.4 million gallons per day (Table 20).

Withdrawals for domestic uses (including watering of livestock) accounted for the largest quantity - 54 percent. Other major withdrawals were for municipal uses - 27 percent, public uses - 11 percent, and commercial uses - 8 percent. Reported industrial and irrigation uses were negligible and have been included under commercial uses. Because of the low average withdrawal rate (4 gpm per well) for the five reported 'industrial' uses, it is unlikely the 'industrial' uses were for other than potable supplies associated with the industries. Average withdrawals from the two reported 'irrigation' uses were inexplicably low - about 3 gpm per well. Details of the commercial uses were unavailable, but it is likely that these uses were predominantly for potable supplies for motels and gas stations.

Major municipal ground-water supplies in northern Ontario served about 27,000 people in 1976 (Table 21). Average consumption was about 105 gpd per capita. Largest users, Kapuskasing and Cochrane, rely solely on ground water. Another large user, Timmins, obtains about 1 mgd from ground-water sources in addition to the 3.4 mgd obtained from surface water.

The dewatering of mines also appears to be a substantial ground-water withdrawal. This information, however, is not contained within the water-well records. Nine gold mining operations reported by Charron (1967) within the study area had a total pumpage of 4.5 mgd.

GROUND-WATER POTENTIAL FOR LOCAL REQUIREMENTS

The quantity of ground water available annually from such a large region, while of interest, is of little practical use to those engaged in determining the availability of ground-water supplies locally. Generally, the availability of a local ground-water supply hinges on three main considerations. These are:

a. the hydraulic characteristics of the aquifer;
b. the extent of and recharge to the aquifer;
c. the quality of the ground water.

Table 20. Estimates of Ground-Water Withdrawals, 1972

	Domestic[1]	Commercial[2]	Municipal	Public	Total
No. of Wells: Moose	1413	86	13	151	1663
Albany	62	7	5	15	89
Severn	-	-	-	4	4
Total No. of Wells	1475	93	18	170	1756
Average Withdrawal per Well(gpm)	2	4	76	4	3
Total Withdrawal (mgd)	4	0.6	2	0.8	7.4
Percent of Total Withdrawal	54	8	27	11	100

1. Includes watering of livestock
2. Includes 5 wells reported for industrial uses and 2 wells for irrigation uses. Average withdrawals per well were 4 gpm and 3 gpm, respectively

Table 21. Major Municipal Ground-Water Supplies in Northern Ontario, 1976

Municipality	Population Served	Design Flow (mgd)	Average Flow (mgd)	Average Consumption (gpd/capita)
Black River-Matheson:				
Holtyre Twp.	380	0.12	-	-
Ramore Twp.	300	0.11	-	-
Cochrane Town	5100	1.25	0.54	105
Fauquier Twp.	900	0.07	0.06	65
Kapuskasing Town	12000	2.16	1.14	95
Timmins:				
Tisdale Twp.	5590	1.73	0.76	135
Whitney Twp.	2000	0.27	0.22	110
Wicksteed Twp.	1460	0.40	0.15	105
All Municipalities	27730	6.11	2.87	103*

* This value is the average of the six Average Consumption numbers in the above column.

Sources of information:

1. Ontario Ministry of the Environment, 1976, Water and sewage treatment works in Ontario.
2. ______, 1976, Operating summary, water supply systems.
3. Water Pollution and Control, 1977, Waterworks plant statistics; Nov.

The hydraulic characteristics of the aquifer will limit the rate of pumping while the extent of and the annual recharge to the aquifer will limit the quantity that can be safely pumped without depleting the ground-water resource. The quality of water will determine its suitability for use and whether or not physical and chemical treatment will be required.

Previous chapters have dealt with these factors on a regional scale and the major aquifer lithologic units have been identified on Map 4. Nevertheless, because of the variability of subsurface materials, site-specific exploratory test drilling should be undertaken to determine the adequacy and suitability of ground-water supplies in places where high-capacity wells are required.

Generally, in the Shield Region the potential for ground-water supplies is best in overburden aquifers; in the Lowland Region the potential is best in bedrock aquifers. In the Shield Region, sand and gravel in eskers and outwash plains offer the greatest potential for the development of high capacity wells (greater than 100 gpm per well). These sand and gravel deposits, while comprising only a small percentage of all the overburden aquifers, are areally well distributed in the Shield Region.

Fine to medium sand related primarily to lacustrine deposits and sand till which comprise the bulk of overburden aquifers, are not as productive as sand and gravel aquifers. Individual wells in sand and sand till aquifers have the potential to yield up to 25 gpm and can likely satisfy domestic and small community requirements.

In large areas of the Shield Region, crystalline rocks are the only water-yielding formations because overburden is either thin or absent. These areas comprise about 30% of the study area and are of little potential for high capacity wells. Individual wells in crystalline rocks are unlikely to yield enough water for other than domestic requirements.

In the Lowland Region, the potential for the development of high capacity wells is greatest in limestone/dolomite. These rocks are areally extensive and underlie about 30% of the study area. However, the quality of water in these rocks varies from a fresh calcium-bicarbonate type water in areas near the Precambrian-Paleozoic contact to a brackish sodium-chloride type water in coastal areas. Therefore, the use of ground water from limestone/dolomite along the coastal areas may be limited by the salinity of the water.

Other aquifers in bedrock in the north are of minor areal extent and not highly productive. Individual wells in bedrock in other than the limestone/dolomite can likely satisfy primarily domestic and small community requirements.

GROUND-WATER POTENTIAL FOR FUTURE DEVELOPMENT

As discussed in the Hydrogeology chapter , the average annual ground-water recharge is considered as the upper limit of ground water available perenially . Sixty percent of this annual recharge, or about 4100 billion gallons per year (11,000 mgd), is assumed to be recoverable, provided adequate aquifers exist. Annual ground-water withdrawals in 1972 amounted to 3 billion gallons (7.4 mgd) or less than 0.1 percent of this annual recoverable recharge.

The fact that 90% of the ground-water use is directed to domestic, public and municipal purposes indicates that ground-water withdrawals in the area are predominantly for potable supplies. Industries requiring large quantities of water in their processes, e.g. pulp and paper, mining, etc., obtain supplies principally from surface-water sources and will likely continue to do so in the future. The population in the northern Ontario study area in the year 2021 is estimated to be 192,000 (Ont. Dept. Treas. Econ. Aff., 1969). Assuming a per capita consumption of 150 gpd of ground water (with no major industrial uses), the annual ground-water consumption in the year 2021 would amount to about 11 billion gallons (29 mgd) or less than 0.3 percent of the annual recoverable recharge.

SUMMARY

The northern watershed of Ontario comprises an area of 212,000 square miles and extends from Hudson Bay and James Bay to the height of land that divides waters flowing north from those flowing south. The five large river basins (Moose, Albany, Attawapiskat, Winisk and Severn) that are the focus of this report, drain a combined area of 176,700 square miles, or about 83% of the total area of the northern watershed. The Ekwan and other small river basins that drain into James Bay and Hudson Bay have not been studied but results from the five major basins may be extrapolated to cover the remaining 17% of the area.

The study area is composed of two major physiographic regions (Map 1): the Precambrian Shield Region in the south and the Hudson Bay Lowland Region in the north.

The bedrock (Map 2) is composed of two major rock groups: Precambrian rocks which are located in the Shield Region and Paleozoic rocks which occur in the Lowland Region. A small patch of Cretaceous rocks is found in the southeastern part of the study area just north of the Precambrian-Paleozoic contact.

The Precambrian rocks consist, for the most part, of granites and gneisses. In certain areas, there are inliers of highly deformed and metamorphosed sedimentary and volcanic rocks. The Paleozoic rocks are divided into 16 formations ranging in age from Ordovician to Devonian. They consist mainly of carbonate rocks of limestone, dolomite, sandy limestone and dolomitic sandstone. The Cretaceous rocks consist of fire clay, micaceous quartz sand and lignite.

The surficial overburden materials (Map 3) include a wide variety of deposits: tills in ground and end moraines, sands and gravels in eskers, esker-kame complexes and in outwash plains, and fine sands, silts and clays in lacustrine, marine and aeolian deposits. The thickness of the drift varies from a few feet to more than 600 feet, being thickest where glaciers filled old bedrock valleys or built end moraines. Glacial drift predominates at the surface in the southern parts of the study area, while marine sediments predominate in the northern parts and constitute the greatest volume of post-glacial deposits in the five basins.

Hydrogeologic interpretations have been based primarily on field investigations and on data obtained from water-well records up to the end of 1972. Additional hydraulic and hydrogeologic information is provided by in situ field transmissibility tests and by laboratory tests of permeabilities and mechanical analyses. Of the 2080 water wells in the study area, 89% are located in the Moose River basin. Most of the 2080 wells are clustered generally in the Cochrane-Timmins area and along the northern route of the Trans-Canada Highway between Hearst and Cochrane (Map 5).

There are four types of overburden materials (lithologic units) which form aquifers, and these are found primarily over Precambrian rocks (Map 4). Ground water is also obtained from aquifers in five different bedrock units, and these units correspond to in situ Paleozoic rocks.

Of the four overburden units, two consist of sand and gravel in eskers and sand and gravel related primarily to outwash deposits in plains and to those bordering esker-kame complexes, end moraines and interlobate moraines. The third unit consists of fine to medium sand primarily of lacustrine origin and referred to in the report as sand aquifers. The fourth unit consists of sand till related primarily to end and interlobate moraines.

Sands and gravels associated with outwash plains and eskers are the most productive overburden aquifers. The mean transmissibility of wells penetrating these aquifers is about 5000 gpd/ft and individual wells average about 200 gpm. Municipal wells in buried sand and gravel aquifers at Kapuskasing and Cochrane, which yield more than 200 gpm each, are examples of the productivity of some of these sand and gravel aquifers.

The sands associated with lacustrine deposits, and the fine sands and boulder deposits that form the matrix of tills, are widely distributed in the Precambrian rock area but are considerably less productive than sands and gravels. The mean transmissibility of aquifers consisting of these materials is low, about 500 gpd/ft, but under favourable hydrogeologic conditions, individual wells may yield up to 25 gpm.

Many wells in the area of Precambrian rocks obtain water from fractured crystalline rocks because the overburden is either thin, absent, or poorly permeable. These rocks exhibit a wide range of hydraulic properties, but in general, the mean transmissibility is low (about 200 gpd/ft) and yields of many individual wells are barely enough for domestic use. Most crystalline rock wells obtain water within 50 feet below bedrock surface.

Aquifers in the five Paleozoic bedrock units consist of limestone/dolomite, sandstone/limestone, sandstone/siltstone, limestone, and carbonaceous shale. The limestone/dolomite rocks are most extensive and aquifers in these rocks have the greatest potential for high-capacity wells. Mean transmissibility of wells penetrating these rocks is about 5000 gpd/ft and individual wells may yield up to 200 gpm. Limited data are available for the sandstone/limestone and sandstone/siltstone units, but it is estimated that wells penetrating these units may yield up to about 25 gpm. No information is available regarding the hydraulic properties of the limestone and carbonaceous shale units.

Data obtained from a network of 40 observation wells indicate that ground-water levels fluctuate generally between 1 to 6 feet and average about 2.5 feet. On the basis of these fluctuations, the annual change of ground water in storage is estimated to be about 4400 billion gallons, of which less than 0.5% or 16 billion gallons occur in bedrock units.

Average annual recharge to ground water has been estimated on the basis of ground-water discharge to rivers in 45 sub-basins that comprise the study area (Map 6). This discharge was assumed to be equivalent to daily streamflow that is equalled or exceeded 90% of the time, and is estimated to be 6800 billion gallons per year (19 billion gpd) in the five major river basins. This recharge is equivalent to an annual infiltration of 2.7 inches over the five basins, or about 10% of the annual precipitation of 26 inches. Sixty percent of the recharge, or about 4100 billion gallons per year (11 billion gpd), is assumed to be recoverable through existing aquifers.

Ground-water quality is indicated by general inorganic chemical analyses of water samples taken from wells and springs shown on Map 7. Ground water in northern Ontario is generally hard to very hard ($<$120 mg/l as Ca CO_3) and with the exception of iron, concentrations of the common inorganic constituents are generally lower than the permissible criteria for public water supplies. Iron often exceeds the permissible criteria of 0.3 mg/l.

Waters from overburden and crystalline rocks are generally less mineralized than those obtained from sedimentary rocks, and are predominantly of a calcium-bicarbonate type. Waters from sedimentary rocks vary from a calcium-bicarbonate type in areas near the Precambrian-Paleozoic contact to a sodium-chloride type in coastal areas. The high salinity of water in limestone/dolomite along the coastal areas may limit its use for domestic purposes.

There is generally very little data available regarding ground-water uses in the five basins. Consequently, information regarding ground-water uses have been interpreted from water-well records on file with the MOE. On the basis of information in these records, total ground-water withdrawals in 1972 are estimated to be 3 billion gallons (7.4 million gpd), which amounts to less than 0.1 percent of the estimated annual recoverable ground water from the five basins. Domestic and municipal uses account for 81% of the total withdrawals, the rest being used by industrial, commercial, irrigation and public facilities. Annual withdrawals in the next 50 years (assuming no major industrial ground-water uses) is estimated to be less than 0.3 percent of the recoverable ground water.

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APPENDIX A

FORMULAE USED IN COMPUTING HYDRAULIC CONSTANTS

REFERENCE	EQUATION NO.
Ferris (1951)	1
Jacob (1950)	2
Jacob (1953)	3
Lohman (1963)	4
Ogden (1965)	5,6
Rorabough (1960)	7
Stallman (1962)	8,9
Theis (1935)	10
Zangar (1953)	11,12

Ferris (1951) equation for the determination of the coefficient of transmissibility:

$$T = \frac{3.7\ (\Delta x)^2\ \ S}{t_o} \qquad .....(1)$$

where:
- Δx = distance corresponding to one log cycle of a semilog plot (ft)
- t_o = average period of stage fluctuation (days)
- S = coefficient of storage
- T = coefficient of transmissibility (gpd/ft)

Jacob (1950) equation for the determination of the coefficient of transmissibility:

$$T = \frac{264\ Q}{\Delta s} \qquad .....(2)$$

where:
- Q = rate of discharge (gpm)
- Δs = change in drawdown over one log cycle (ft)
- T = coefficient of transmissibility (gpd/ft)

Jacob (1953) equation for the determination of the coefficient of storage:

$$S = \frac{(\gamma m \theta)}{E_w}\ \left(\frac{1}{1-c}\right) \qquad .....(3)$$

where:
- γ = specific weight of water at the prevailing temperature, 6^oC (62.42 lbs/ft^3)
- m = thickness of aquifer (ft)
- θ = porosity of aquifer
- c = tidal efficiency
- E_w = bulk modulus of elasticity of water (approximately 300,000 lb/in^2)
- S = coefficient of storage

Lohman (1963) equation for the determination of the coefficient of transmissibility:

$$S = \frac{2.5\times10^{-4} \; T \, t_m/r^2}{\text{antilog} \, (s/\Delta s)} \qquad \text{.....(4)}$$

where:

t_m	=	time since pumping begun (mins)
s	=	drawdown at time t_m (ft)
Δs	=	drawdown over one log cycle of time (ft)
r	=	distance between the pumping well and the observation well (ft); or radius of pumped well if no observation well is available (ft)
S	=	coefficient of storage
T	=	coefficient of transmissibility (gpd/ft)

Ogden (1965) method for the determination of the coefficient of transmissibility based on one drawdown:

$$u \times w(u) = \frac{1.56 \, r^2 \, S \, s}{114.6 \, Q \, t} \qquad \text{.....(5)}$$

$$u = \frac{1.56 \, r^2 \, S}{T \, t} \qquad \text{.....(6)}$$

where:

s	=	drawdown (ft)
r	=	distance from centre of pumped well to centre of the observation well (ft)
Q	=	discharging rate of the pumped well (gpm)
T	=	coefficient of transmissibility of the aquifer (gpd/ft)
S	=	coefficient of storage
t	=	time since pump started (days)
$w(u)$	=	an evaluation of a definite integral of

$$\int_u^{\infty} \frac{e^{-u}}{u} \, du$$

for which a table has been published (Wenzel, 1942)

Rorabough (1960) equation for the determination of the coefficient of transmissibility:

$$T = \frac{5.8\ a^2\ S}{t_r} \qquad \text{.....(7)}$$

where: a = distance between an observation well and a ground-water divide (feet)

t_r = a critical time corresponding to one log cycle of a semilog plot of water level recession versus time (days)

S = coefficient of storage

T = coefficient of transmissibility (gpd/ft)

Stallman (1962) equations for the determination of the coefficient of transmissibility:

$$s = s_o\ D(u)_h = s_o \left[1 - \frac{2}{\sqrt{\pi}} \int_0^{\frac{x}{2\sqrt{Tt/S}}} e^{-u^2}\ du \right] \qquad \text{.....(8)}$$

$$u^2 = \frac{1.56\ x^2\ S}{T\ t} \qquad \text{.....(9)}$$

where: $D(u)_h$ = drain function of u for constant head h

x = distance from stream to an observation well in which the decline in artesian head is a result of change in river stage (ft)

t = time since a sudden change in river stage (days)

s = water-level recession in the observation well (ft)

s_o = difference between initial and final river stage (ft)

S = coefficient of storage

T = coefficient of transmissibility (gpd/ft)

Note: To use these equations, a type curve of $D(u)_h$ versus corresponding values of u^2 is necessary

Theis (1935) equation for the determination of the coefficient of transmissibility:

$$T = \frac{264\ Q}{\Delta s'} \log_{10}\left(\frac{t}{t'}\right) \qquad .....(10)$$

where:
- t = time since pump started (days)
- t' = time since pump stopped (days)
- $\Delta s'$ = change in residual drawdown (ft) between t and t'
- Q = rate of discharge (gpm)
- T = coefficient of transmissibility (gpd/ft)

Zangar (1953) equations for the determination of the coefficient of permeability:

$$K = \frac{1}{2\pi r_1} \frac{Q}{H} \text{ for spherical flow} \qquad .....(11)$$

and

$$K = \frac{1}{C_s\ r_1} \frac{Q}{H} \text{ for hemispherical flow} \qquad .....(12)$$

where:

$$C_s = \frac{La}{r_1} \quad \frac{2\pi}{\ln\left(\frac{La}{r_1}\right)}$$

- K = coefficient of permeability (ft/sec)
- r_1 = radius of well (ft)
- H = effective head differential (ft)
- L_a = length of active or open hole (ft)
- Q = steady flow (ft^3/sec)

APPENDIX B

GRAPHS SHOWING PUMPING TEST DATA

OF

TEST HOLES

Graphs are arranged alphabetically by district and by well number within each district. Locations of test holes are shown on Map 5. For bedrock wells, "total screened footage" refers to the length of the open, uncased hole.

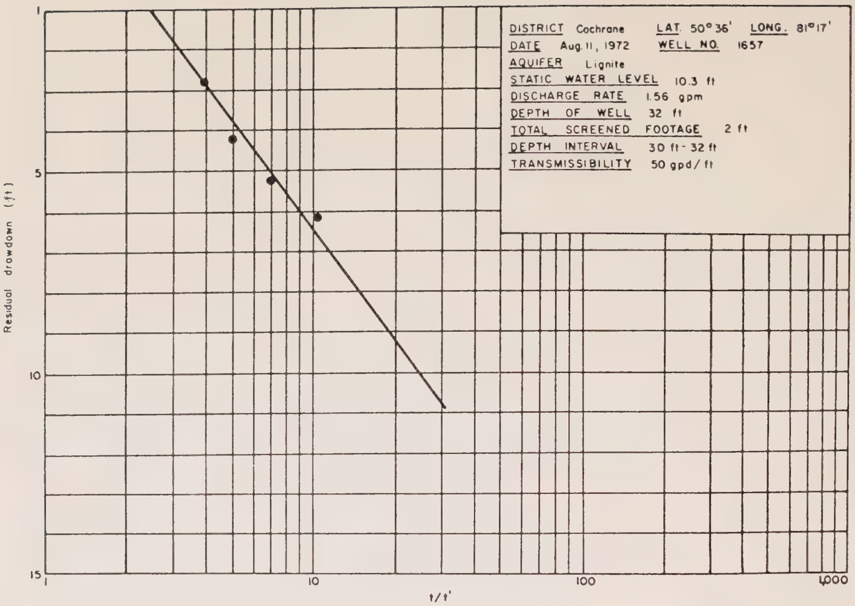


Figure 26. Residual drawdown curve for pumping test on test hole #1657, Moose River basin.

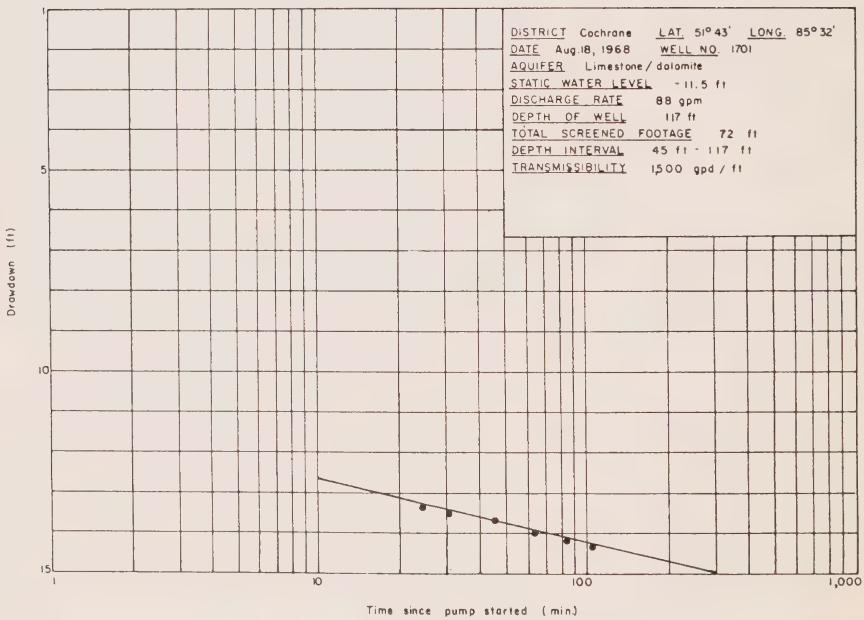


Figure 27. Time-drawdown curve for pumping test on test hole #1701, Albany River basin.

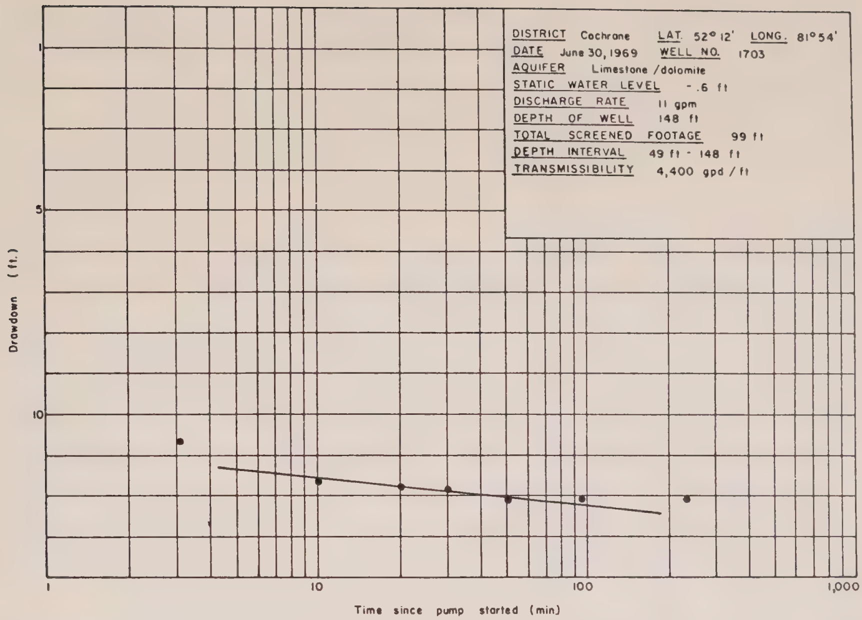


Figure 28. Time-drawdown curve for pumping test on test hole #1703, Albany River basin.

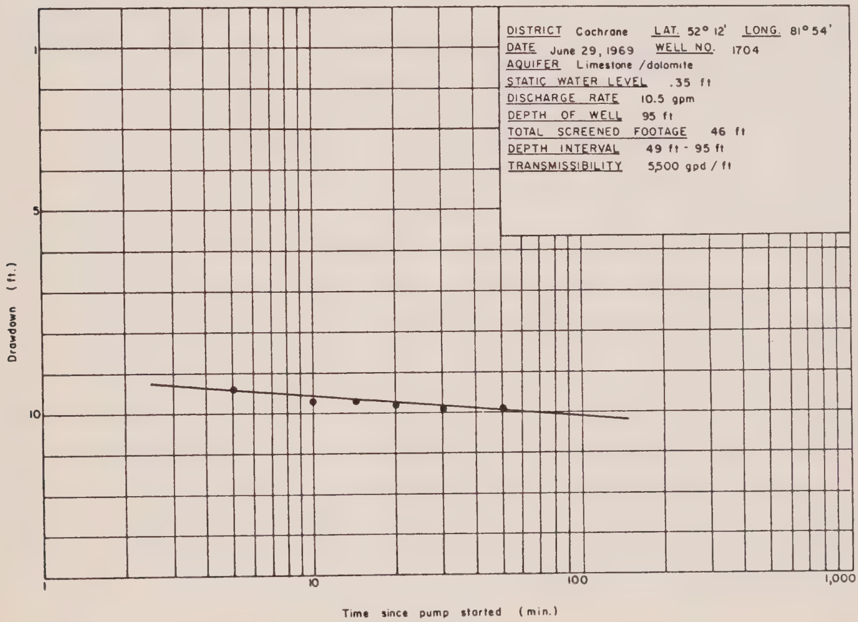


Figure 29. Time-drawdown curve for pumping test on test hole #1704, Albany River basin.

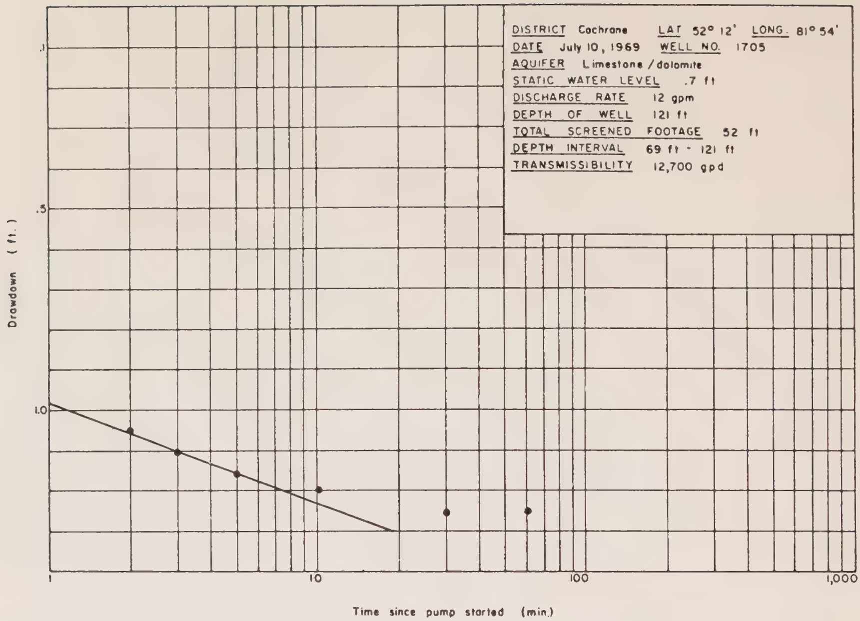


Figure 30. Time-drawdown curve for pumping test on test hole #1705, Albany River basin.

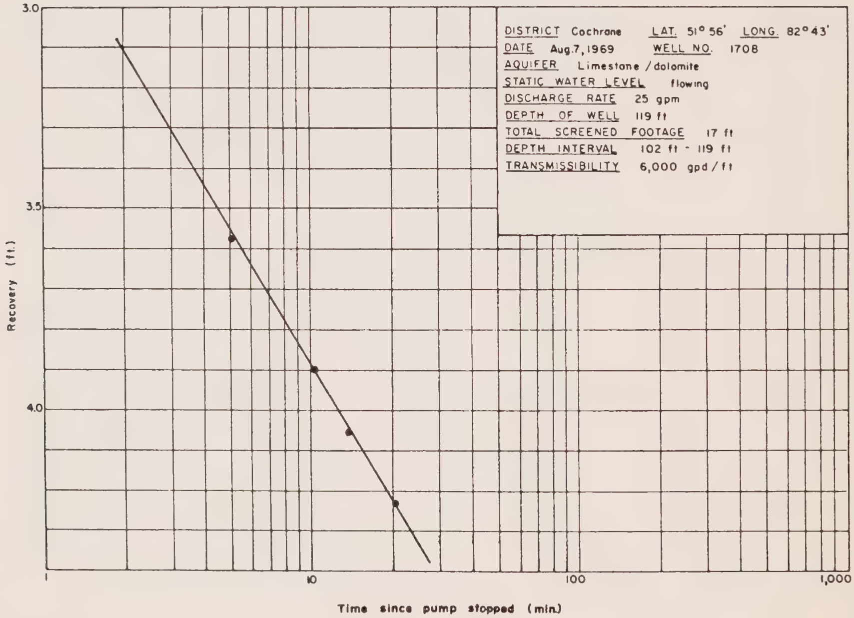


Figure 31. Time-recovery curve for pumping test on test hole #1708, Albany River basin.

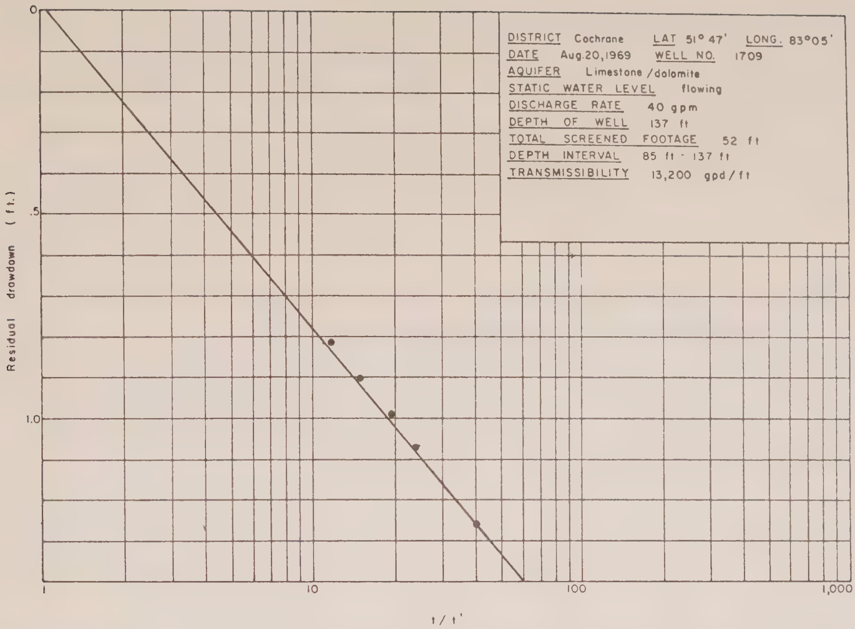


Figure 32. Residual drawdown curve for pumping test on test hole #1709, Albany River basin.

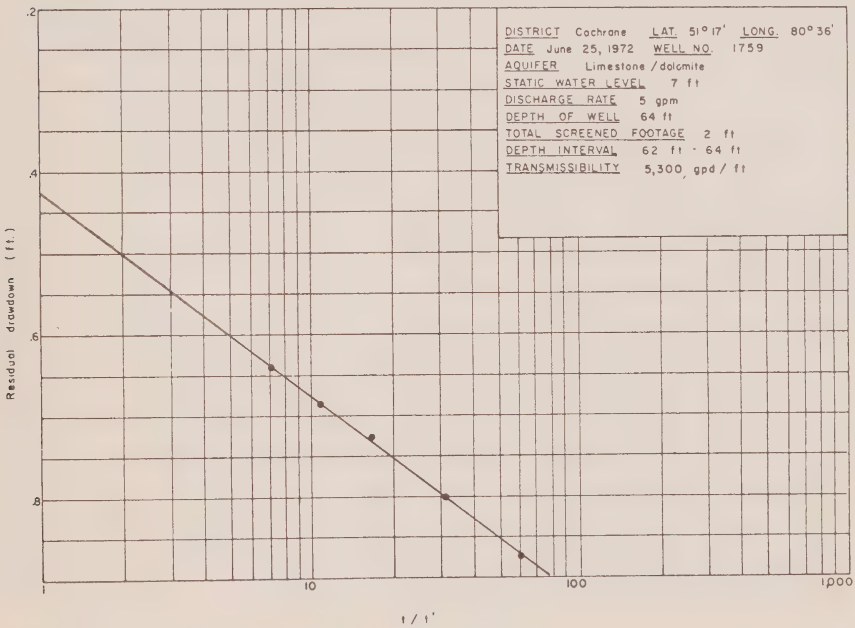


Figure 33. Residual drawdown curve for pumping test on test hole #1759, Moose River basin.

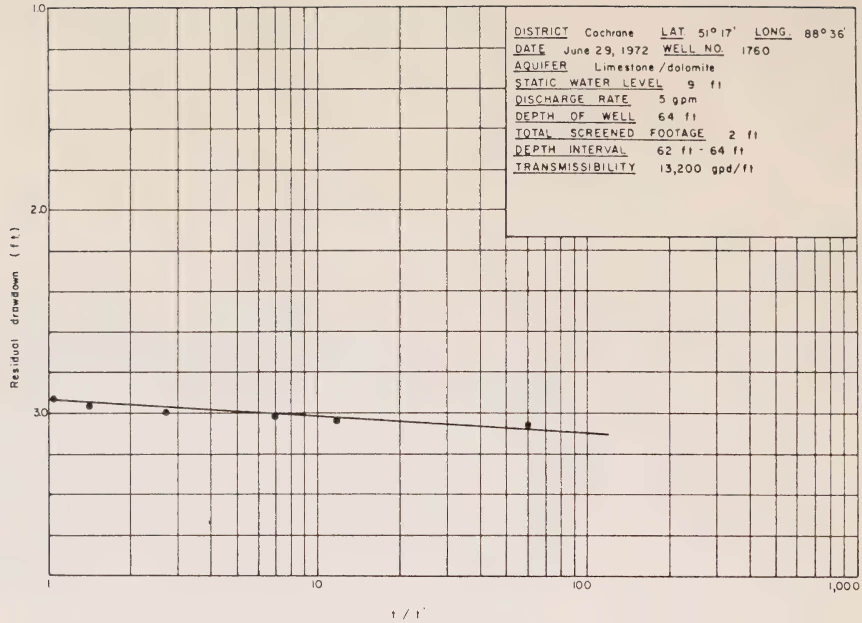


Figure 34. Residual drawdown curve for pumping test on test hole #1760, Moose River basin.

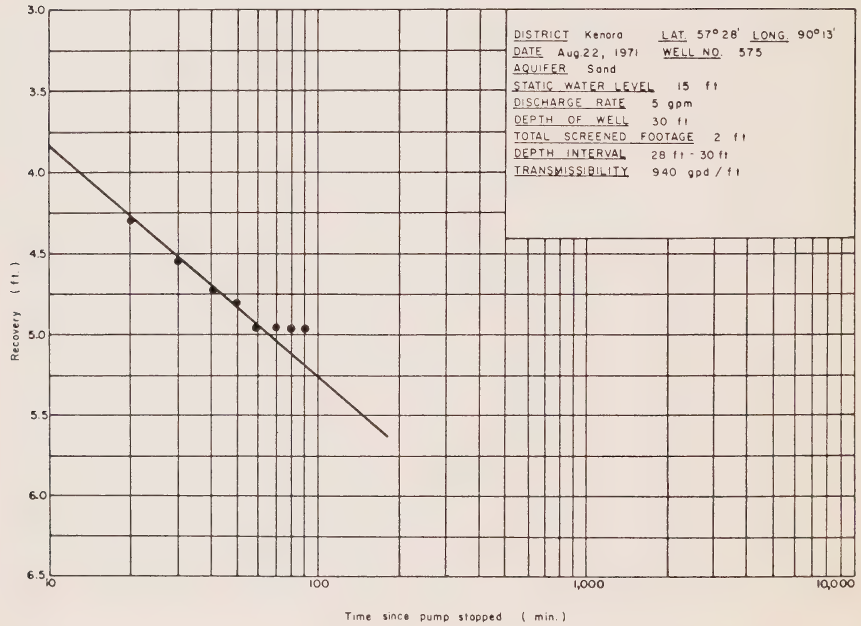


Figure 35. Time-recovery curve for pumping test on test hole #575, Attawapiskat River basin.

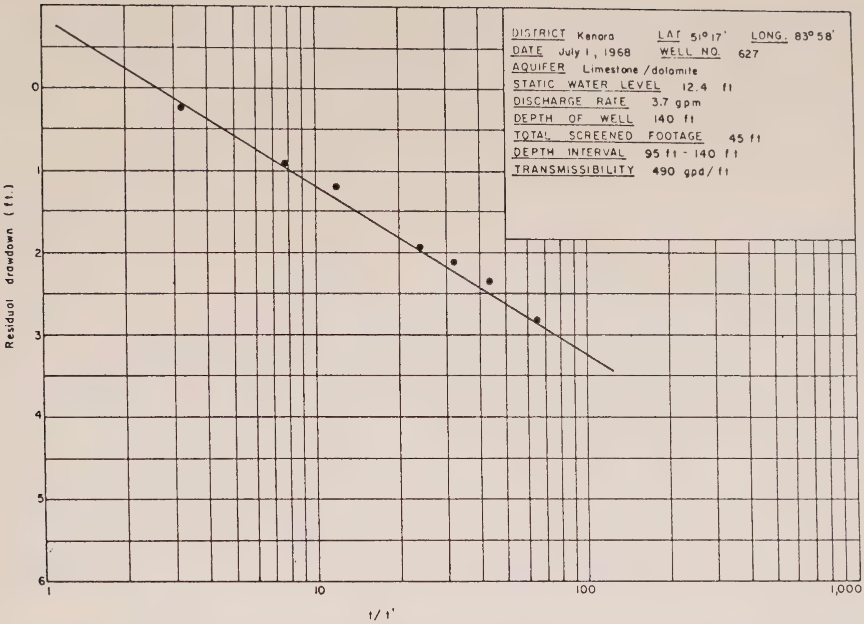


Figure 36. Residual drawdown curve for pumping test on test hole #627, Albany River basin.

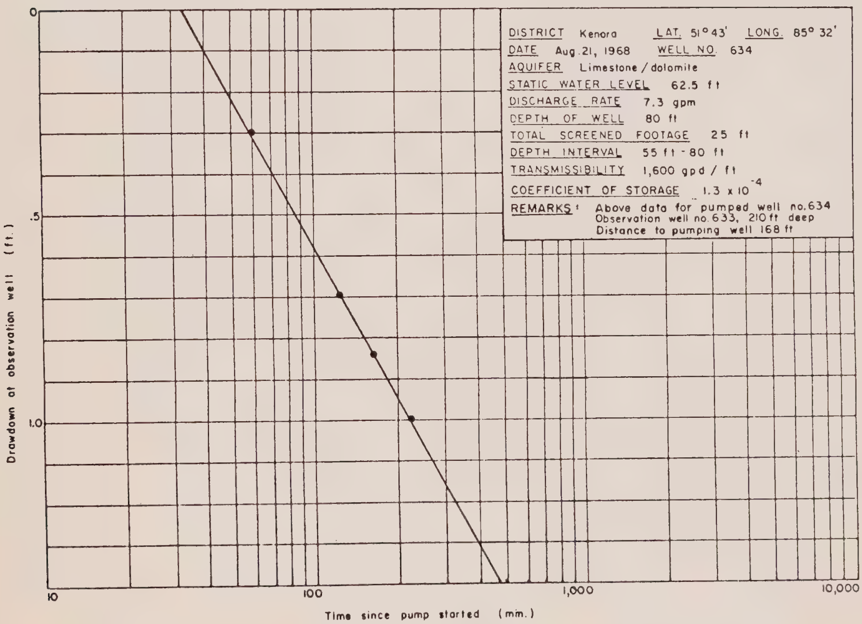


Figure 37. Time-drawdown curve for observation well #633, pumping test on test hole #634,
Albany River basin.

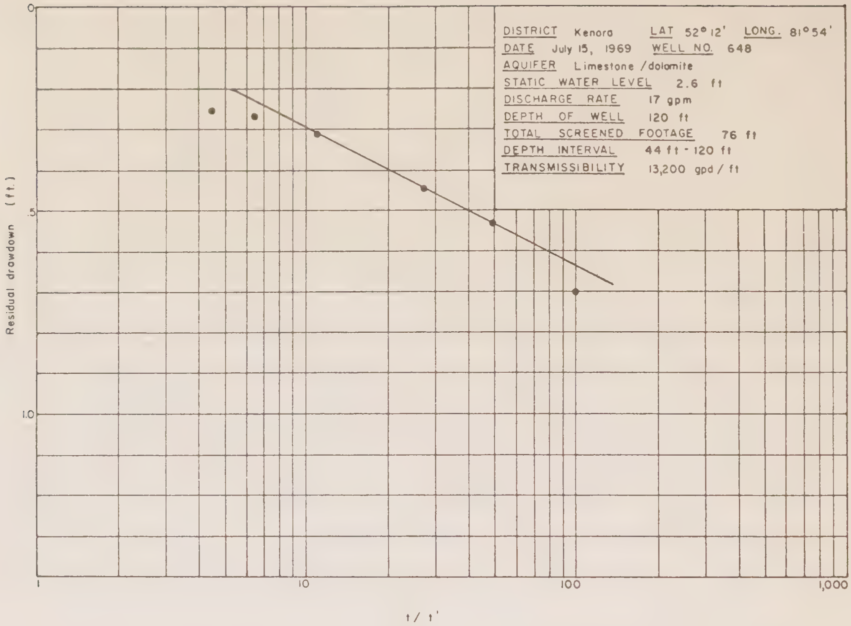


Figure 38. Residual drawdown curve for pumping test on test hole #648, Albany River basin.

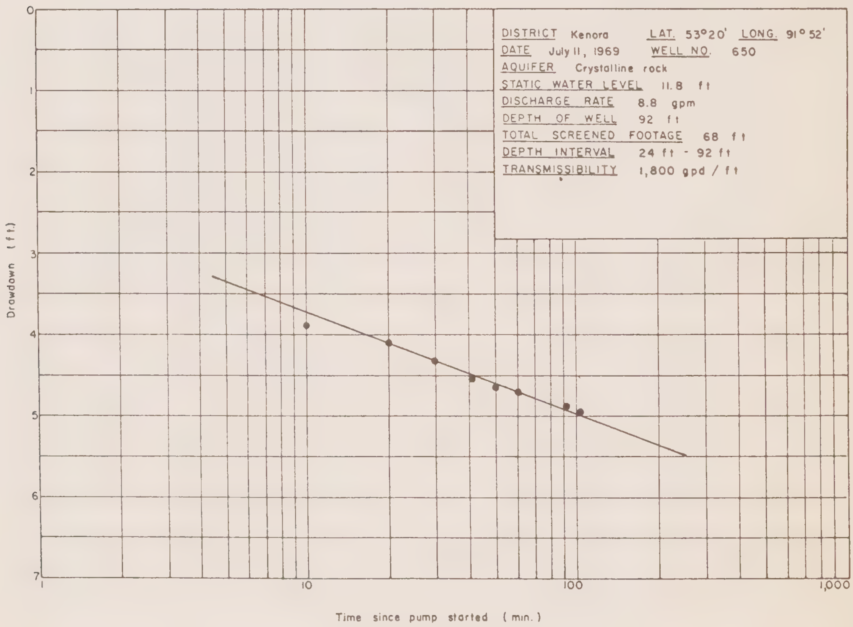


Figure 39. Time-drawdown curve for pumping test on test hole #650, Severn River basin.

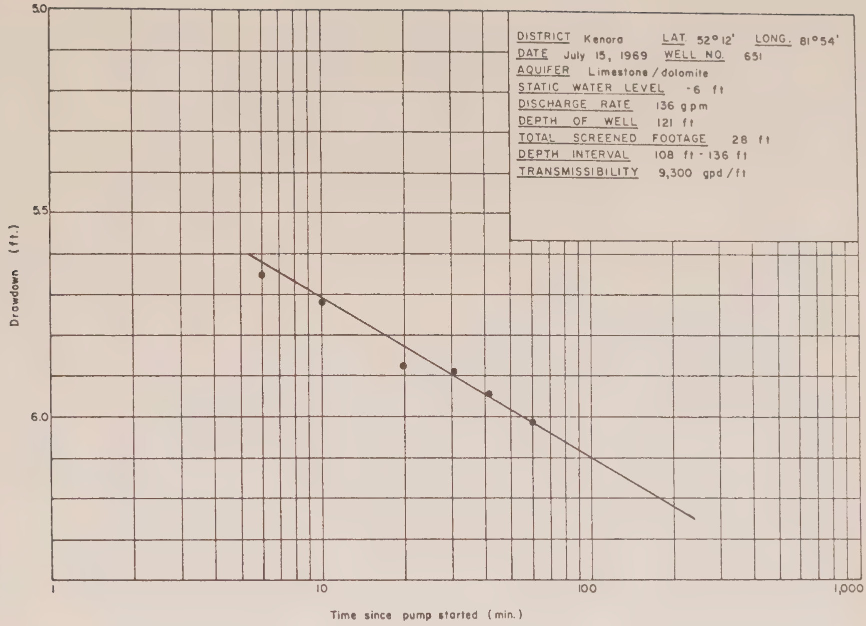


Figure 40. Time-drawdown curve for pumping test on test hole #651, Albany River basin.

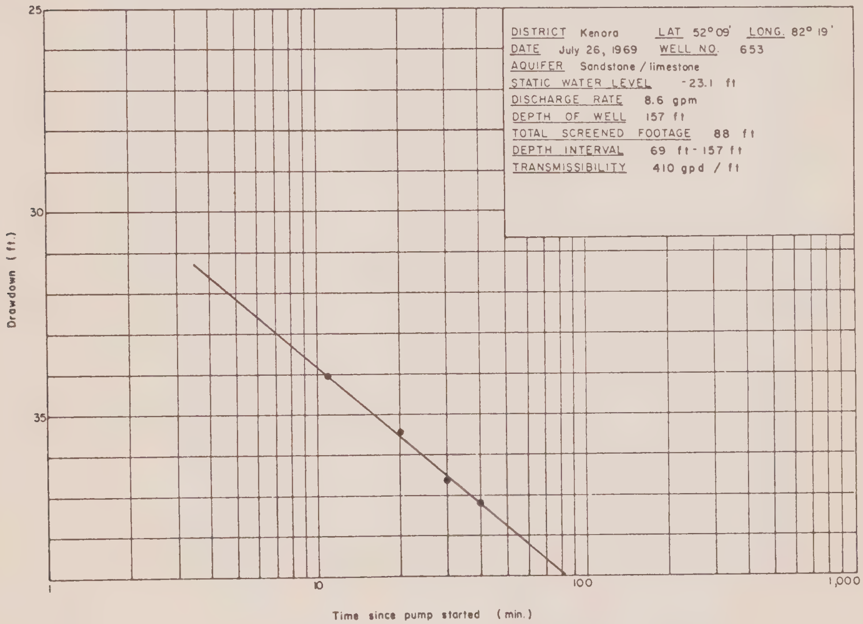


Figure 41. Time-drawdown curve for pumping test on test hole #653, Albany River basin.

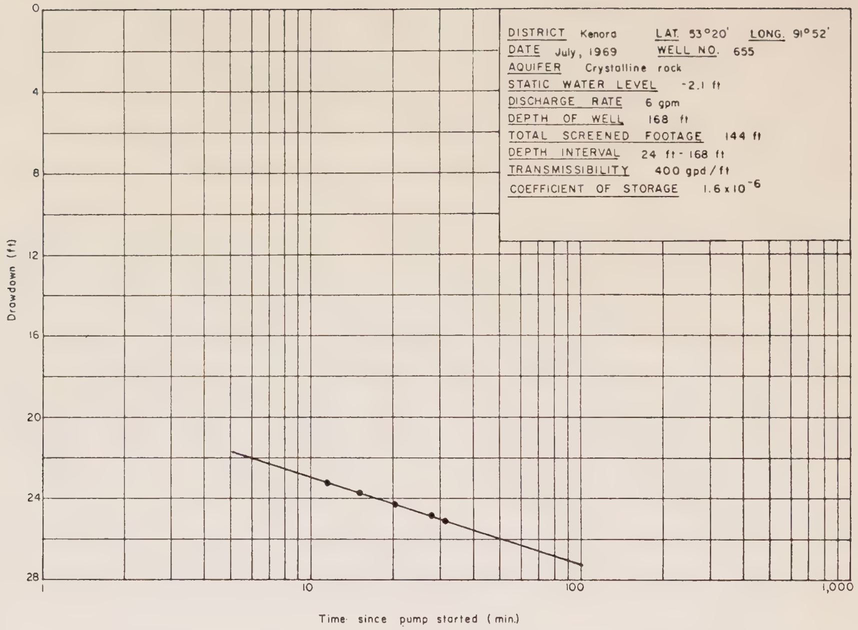


Figure 42. Time-drawdown curve for pumping test on test hole # 655, Severn River basin.

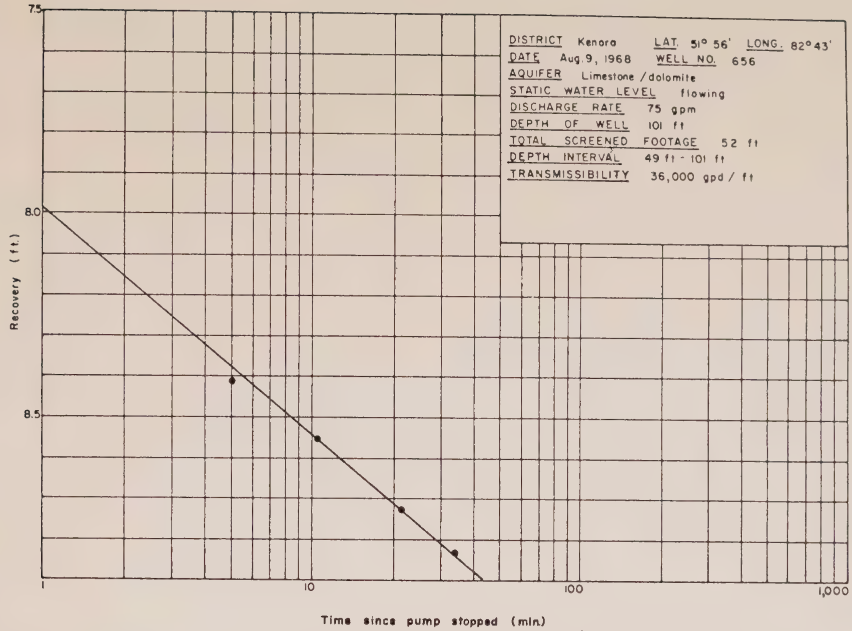


Figure 43. Time-recovery curve for pumping test on test hole #656, Albany River basin.

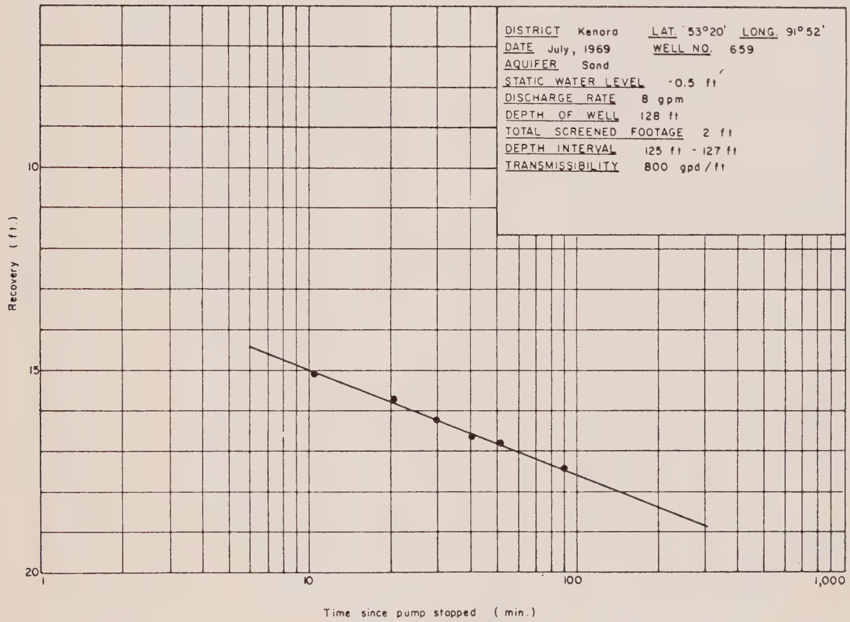


Figure 44. Time-recovery curve for pumping test on test hole #659, Severn River basin.

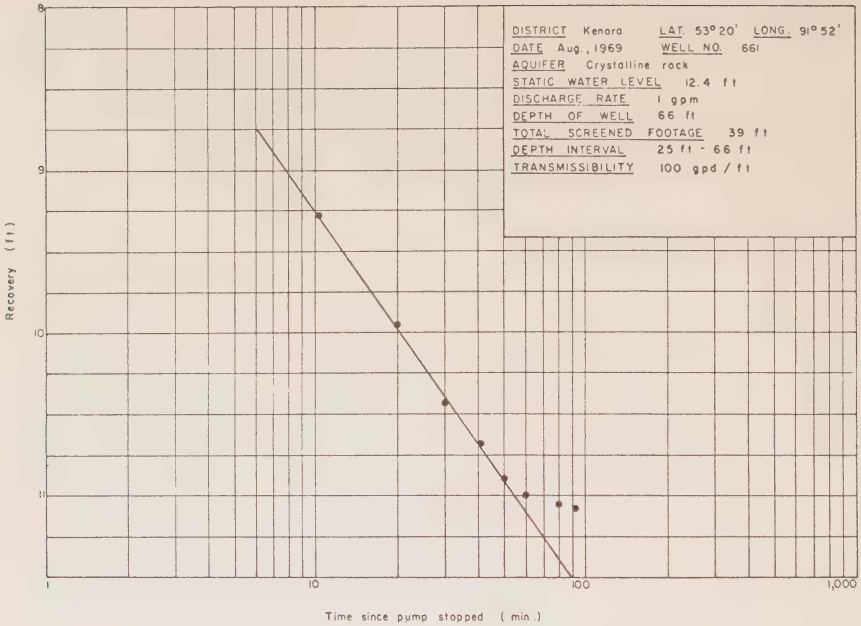


Figure 45. Time-recovery curve for pumping test on test hole #661, Severn River basin.

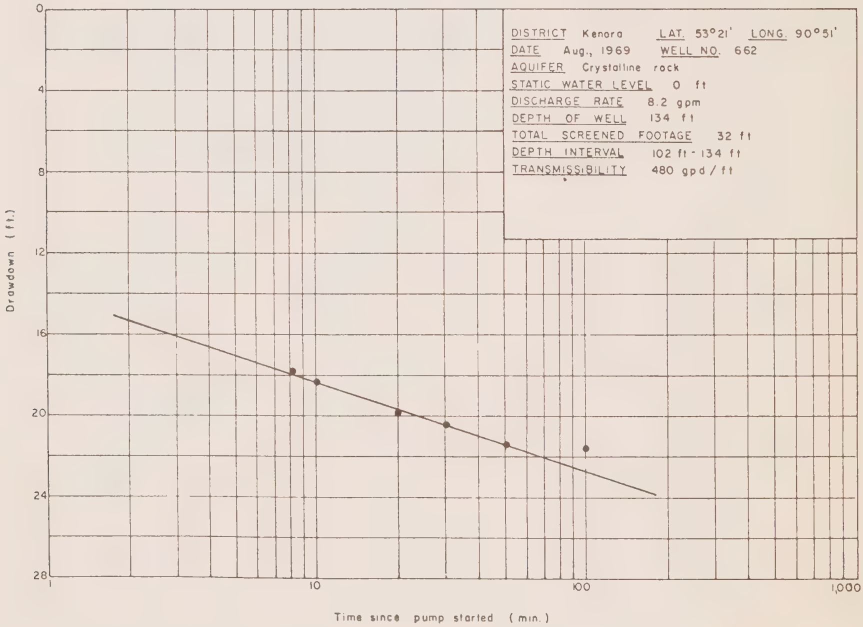


Figure 46. Time-drawdown curve for pumping test on test hole #662, Severn River basin.

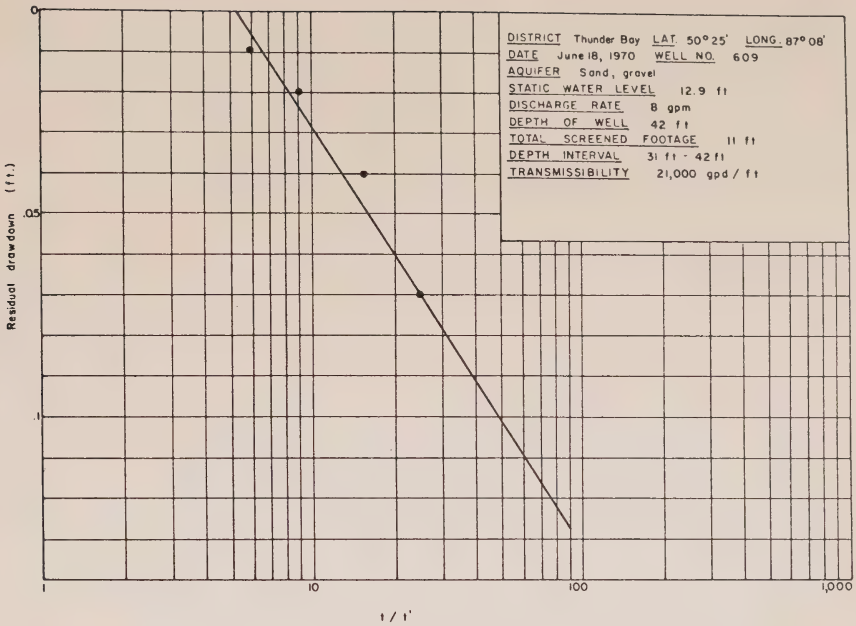


Figure 47. Residual drawdown curve for pumping test on test hole #609, Albany River basin.

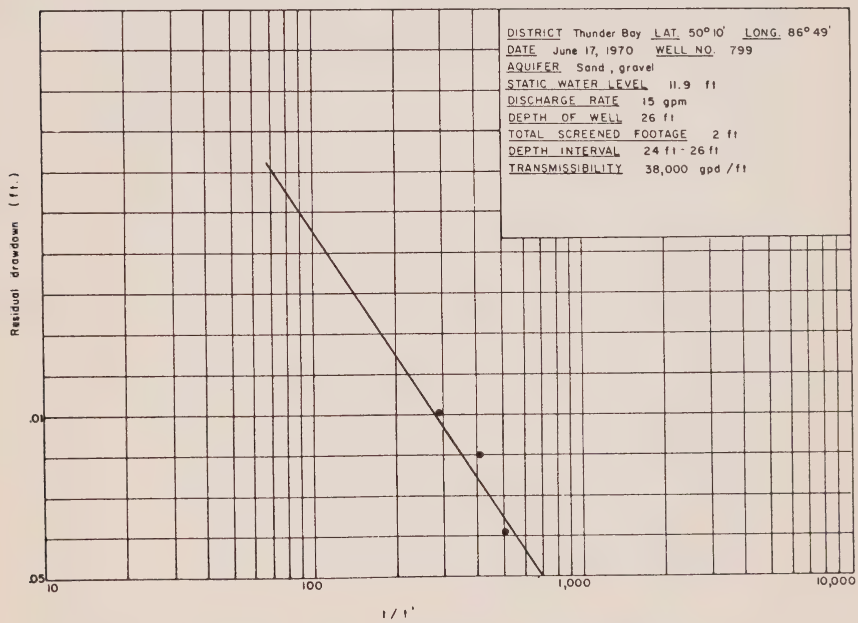


Figure 48. Residual drawdown curve for pumping test on test hole #799, Albany River basin.

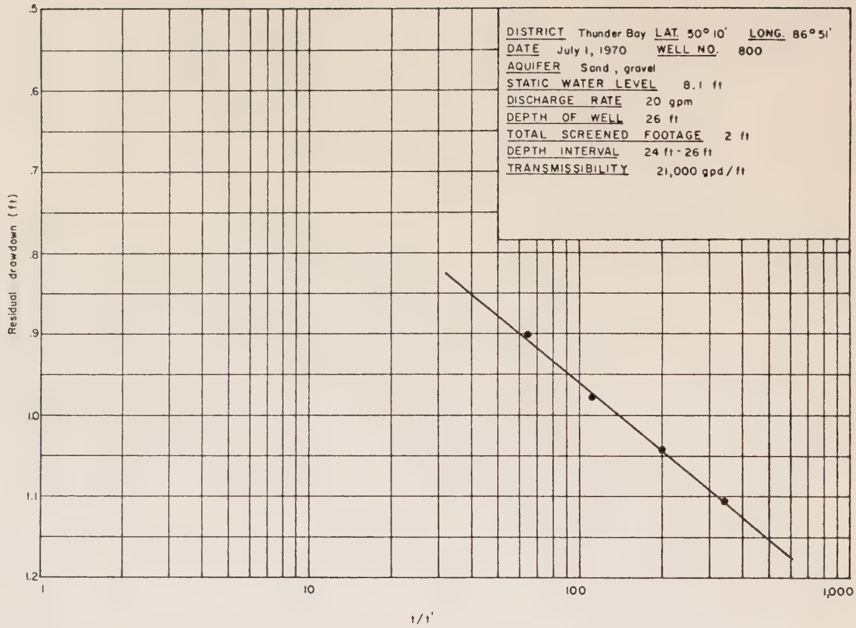


Figure 49. Residual drawdown curve for pumping test on test hole #800, Albany River basin.

APPENDIX C

HISTORY OF OBSERVATION WELLS

IN

NORTHERN ONTARIO

1973

(Observation well locations are shown on Map 6)

HISTORY OF OBSERVATION WELLS IN NORTHERN ONTARIO, 1973

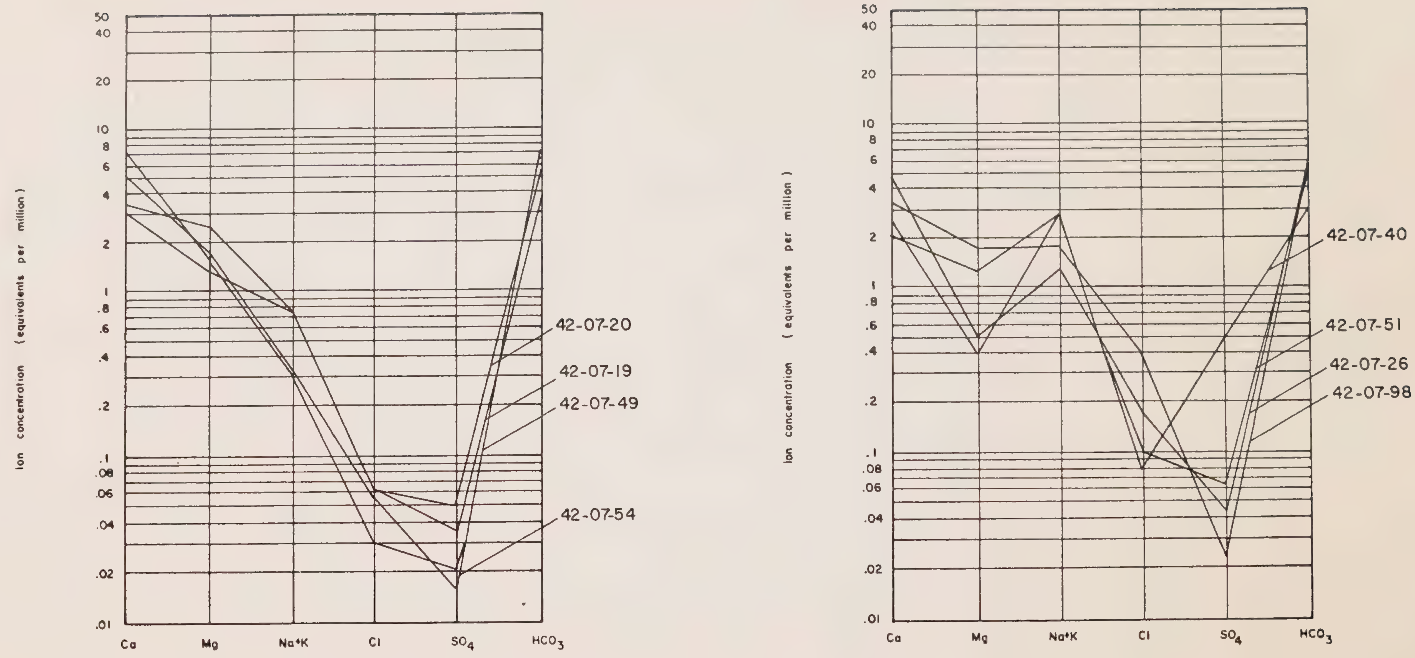
OBSERVATION WELL NO.	WATER WELL RECORD NO.	LOCATION LAT °	'	LONG °	'	DEPTH (ft)	AQUIFER OR FORMATION	PERIOD AND TYPE OF RECORD	
MOOSE RIVER BASIN									
42-05-002R	1759	51	17	80	36	64	limestone/ dolomite	Jul.-Oct. 1973,	C
42-05-003R	1761	51	17	80	36	65	limestone/ dolomite	Jul.-Oct. 1973,	C
ALBANY RIVER BASIN									
43-05-001-1R	594	50	20	87	05	60	silt, clay	from Jun. 1969,	C
43-05-002-1	609	50	25	87	08	42	f.sand,gravel	from Jun. 1969,	P
43-05-002-2	609	50	25	87	08	33	f.sand,gravel	from Jun. 1969,	P
43-05-003R	1461	50	04	84	08	120	sand,gravel	from Jun. 1969,	C
43-05-004R	627	51	17	83	58	150	limestone	from Aug. 1968,	C
43-05-007-1	598	50	20	87	05	65	sand,silt	from Jun. 1969,	P
43-05-008-2	597	50	20	87	05	67	clay	from Aug. 1969,	P
43-05-009	1960	50	04	84	08	199	gravel	from Jun. 1969,	P
43-05-014-1	759	50	10	86	49	27	sand,gravel	Jul. 1970-Dec. 1973,	P
43-05-014-2	798	50	10	86	49	93.5	sand till	from Aug. 1970,	P
43-05-014-3	802	50	10	86	49	46	sand,gravel	from Aug. 1970,	P
43-05-014-4	796	50	10	86	49	93.5	sand till	from Dec. 1970,	P
43-05-015-2	794	50	10	86	50	95	sand till	from Sept. 1970,	P
43-05-015-1R	795	50	10	86	50	25	sand	from Jul. 1970,	C
43-05-015-3	793	50	10	86	50	45	silt,sand	from Jul. 1970,	P
43-05-016-1	800	50	10	86	51	27	sand,gravel	from Jul. 1970,	P
43-05-016-2R	803	50	10	86	51	68	sand till	from Jul. 1970,	C
43-05-016-3	792	50	10	86	51	45	sand	from Jul. 1970,	P
43-05-017-1	790	50	12	86	42	30	sand	from Aug. 1970,	P
43-05-017-2	790	50	12	86	42	15	silt	from Sept. 1970,	P
43-05-018	789	50	12	86	40	50	sand	from Sept. 1970,	P
43-05-024R	952	51	12	86	45	48	sand,gravel	from May 1973,	C
ATTAWAPISKAT RIVER BASIN									
44-05-001R	614	51	51	89	36	36.5	fine sand	from Aug. 1967,	C
44-05-002-1	578	51	27	90	13	26	sand,gravel	from Nov. 1971,	P
44-05-002-2	577	51	27	90	13	41	sand,gravel	from Nov. 1971,	P
44-05-003	569	51	27	90	13	40.5	sand,gravel	from Oct. 1971,	P
44-05-004	570	50	27	90	13	40	sand,gravel	from Nov. 1971,	P
44-05-005R	571	51	27	90	13	69	sand,gravel	from Nov. 1971,	C
44-05-006-1	572	51	29	90	11	52	sand,gravel	from Nov. 1971,	P
44-05-006-2	572	51	29	90	11	14	fine sand	from Nov. 1971,	P
44-05-007-1	573	51	29	90	11	20	sand,silt	from Nov. 1971,	P
44-05-007-2R	573	51	29	90	11	9.8	f.sand,silt	from Nov. 1971,	C
44-05-008-1	574	51	29	90	12	40	sand,gravel	from Nov. 1971,	P
44-05-008-2	574	51	29	90	12	36	sand,gravel	from Nov. 1971,	P
44-05-009	575	51	28	90	13	30	sand	from Nov. 1971,	P
44-05-010	576	51	28	90	13	53	sand,gravel	from Nov. 1971,	P
44-05-011	NA	51	27	90	14	8	sand,silt	from Nov. 1971,	P
SEVERN RIVER BASIN									
47-05-001R	662	53	21	90	50	134	schist	from Jul. 1970,	C

C: Continuous record
P: Periodic measurements
NA: Not available

APPENDIX D

MAJOR-ION CHEMISTRY OF GROUND WATER

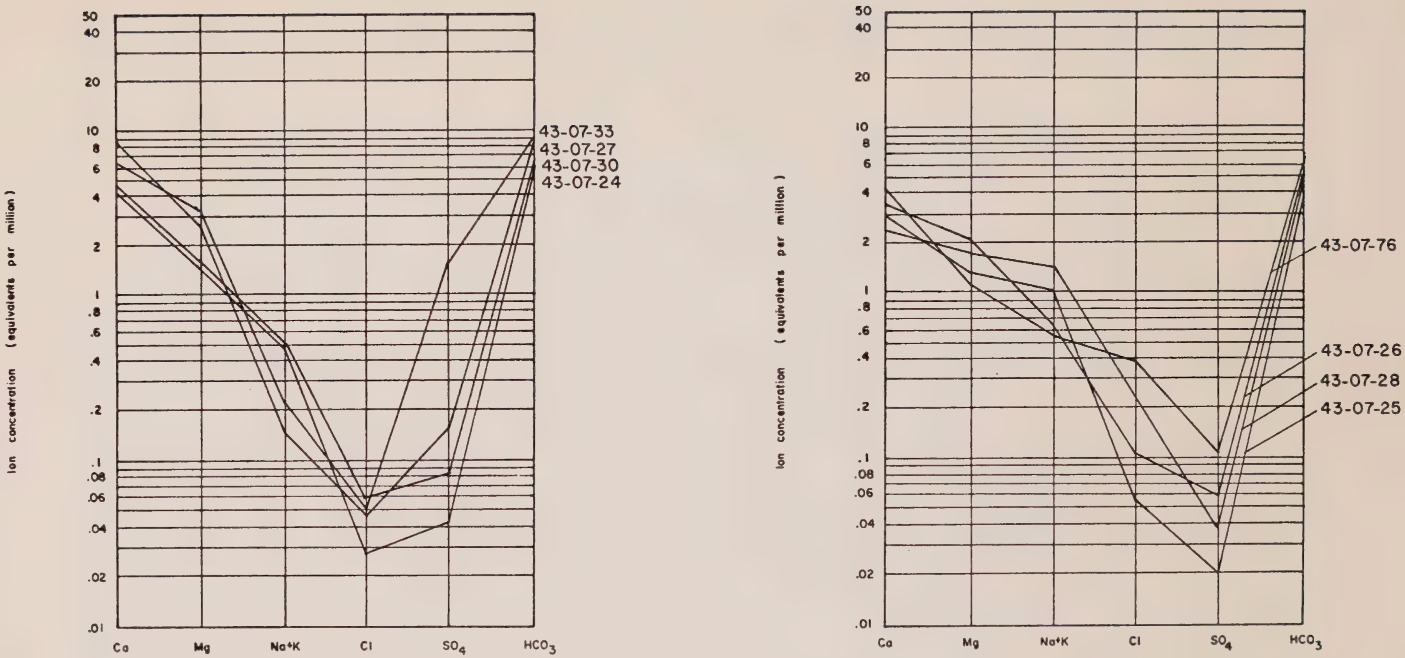
(Sample locations are shown on Map 7)



Calcium-bicarbonate type, Mg > Na, Cl > SO_4

Calcium-bicarbonate type, Mg < Na, Cl > SO_4

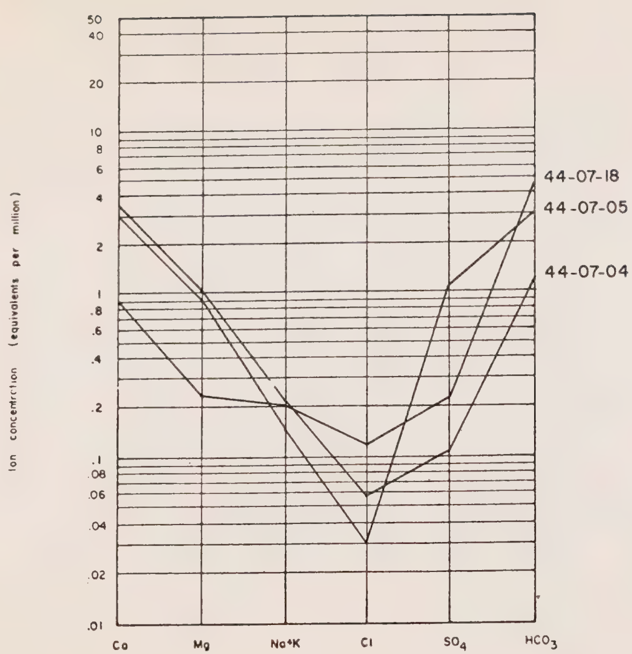
Figure 50. Major-ion chemistry of ground water in crystalline rocks, Moose River basin.



Calcium-bicarbonate type, Mg > Na, SO_4 > Cl

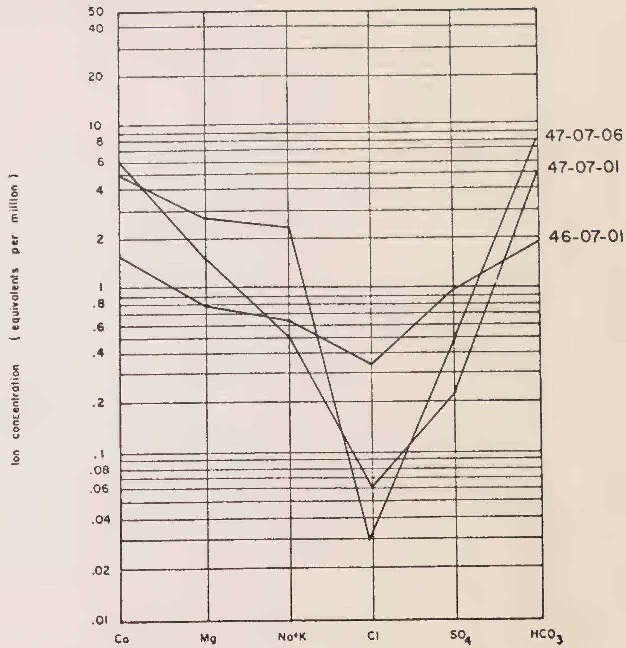
Calcium-bicarbonate type, Mg > Na, SO_4 < Cl

Figure 5l. Major-ion chemistry of ground water in crystalline rocks, Albany River basin.



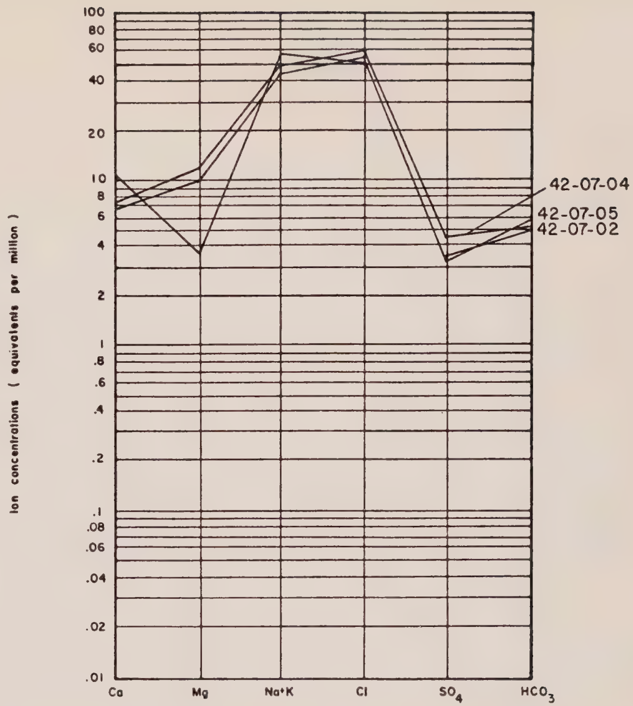
Calcium - bicarbonate type, Mg > Na, SO_4 > Cl

Figure 52. Major-ion chemistry of ground water in crystalline rocks, Attawapiskat River basin.



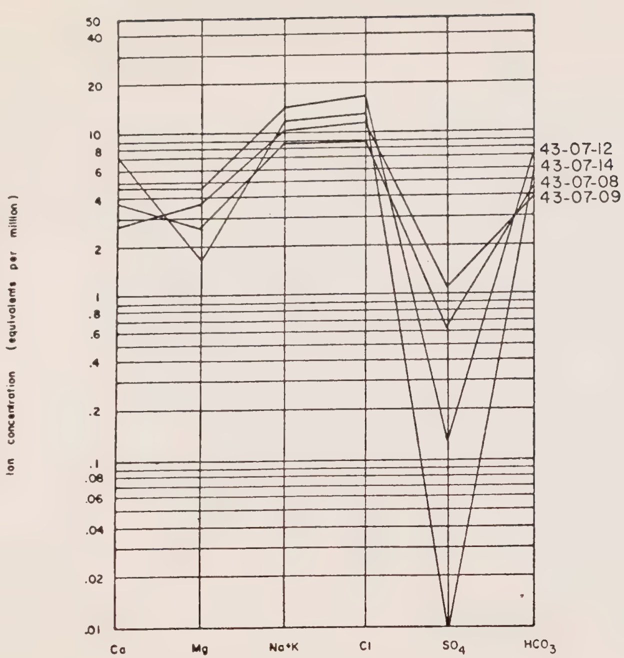
Calcium - bicarbonate type, Mg > Na, SO_4 > Cl

Figure 53. Major-ion chemistry of ground water in crystalline rocks, Winisk and Severn River basins.

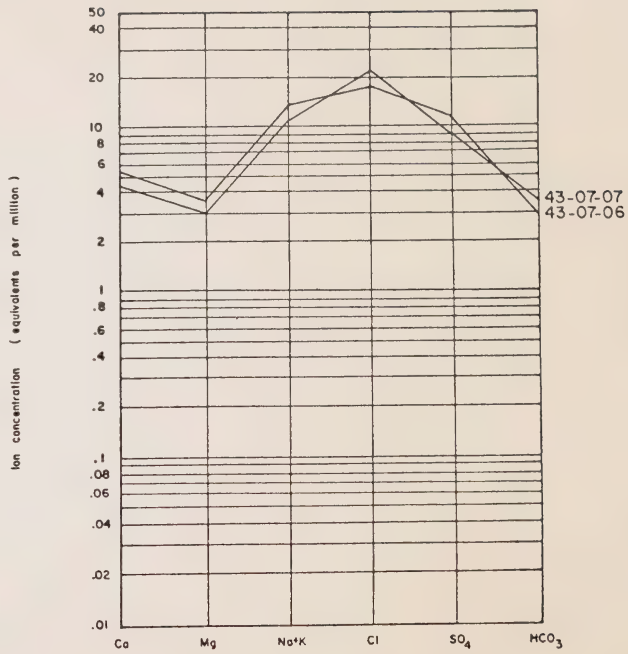


Sodium-chloride type , Mg > Ca , $HCO_3 > SO_4$

Figure 54. Major-ion chemistry of ground water in sedimentary rocks, Moosonee, Moose River basin.

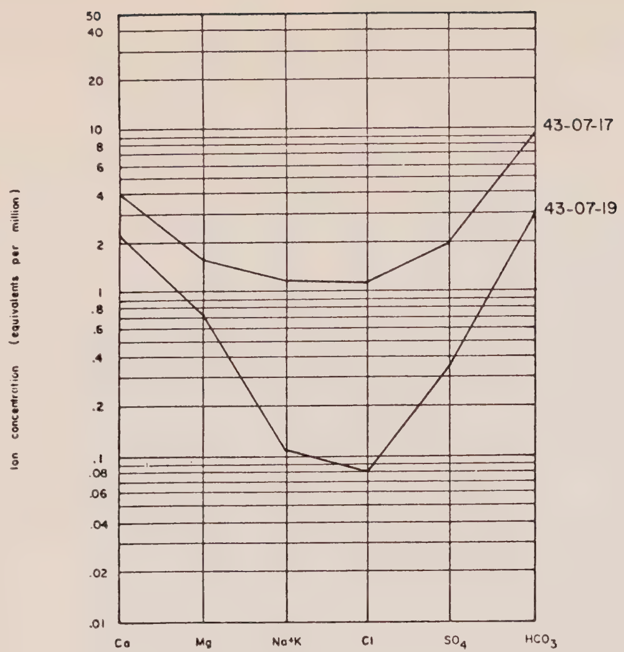


Sodium-chloride type, Ca > Mg, $SO_4 < HCO_3$

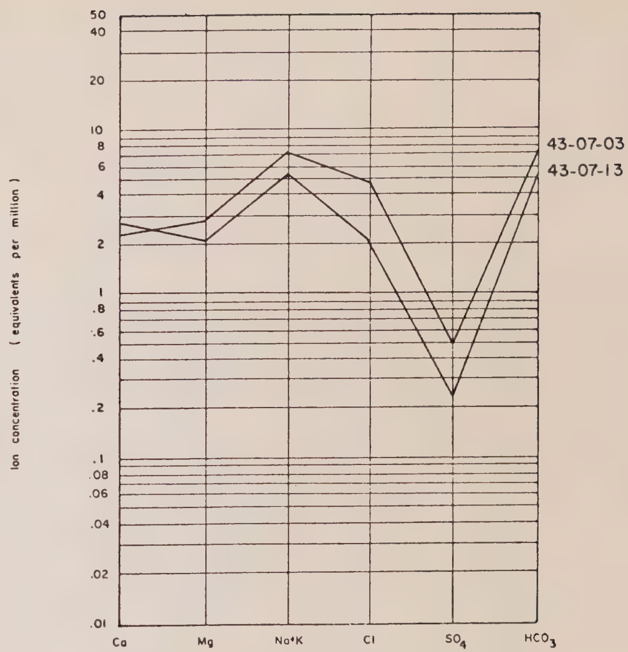


Sodium-chloride type, Ca > Mg, $HCO_3 < SO_4$

Figure 55. Major-ion chemistry of ground water in sedimentary rocks, Albany River basin.

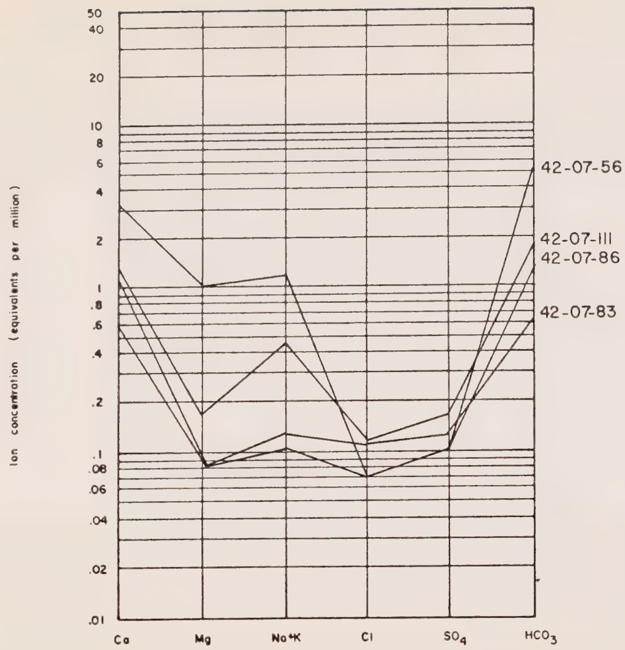


Calcium-bicarbonate type, Mg > Na, Cl < SO_4

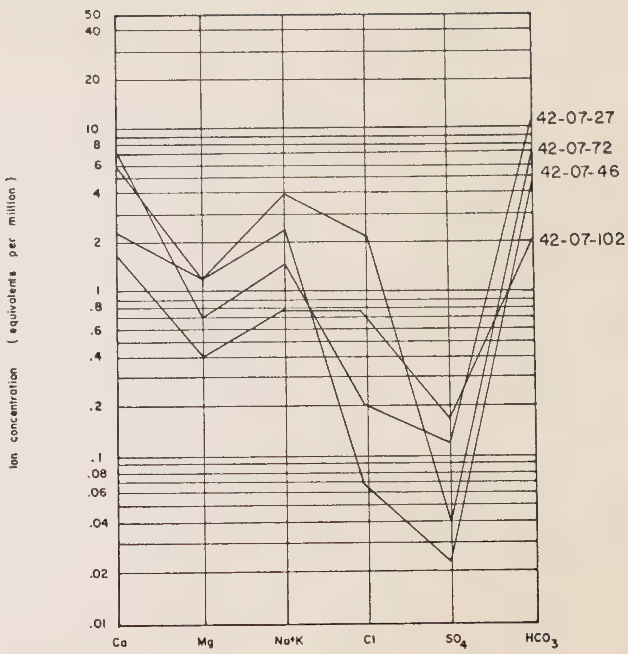


Sodium-bicarbonate type, Mg ≈ Ca, Cl > SO_4

Figure 56. Major-ion chemistry of ground water in sedimentary rocks, Albany River basin.

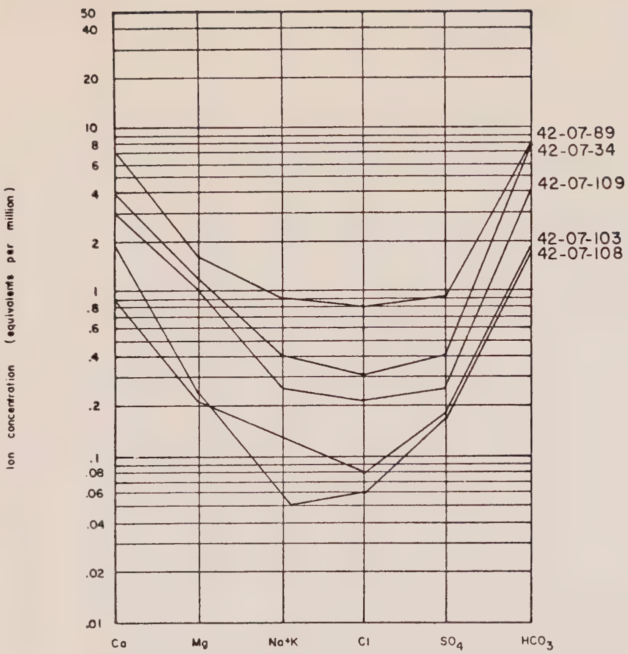


Calcium-bicarbonate type, Na > Mg, SO_4 > Cl

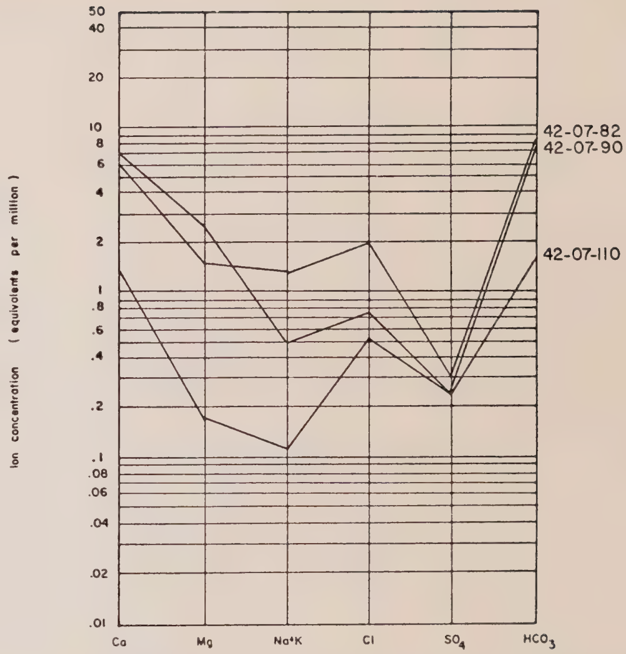


Calcium-bicarbonate type, Na > Mg, Cl > SO_4

Figure 57. Major-ion chemistry of ground water in overburden, Moose River basin.

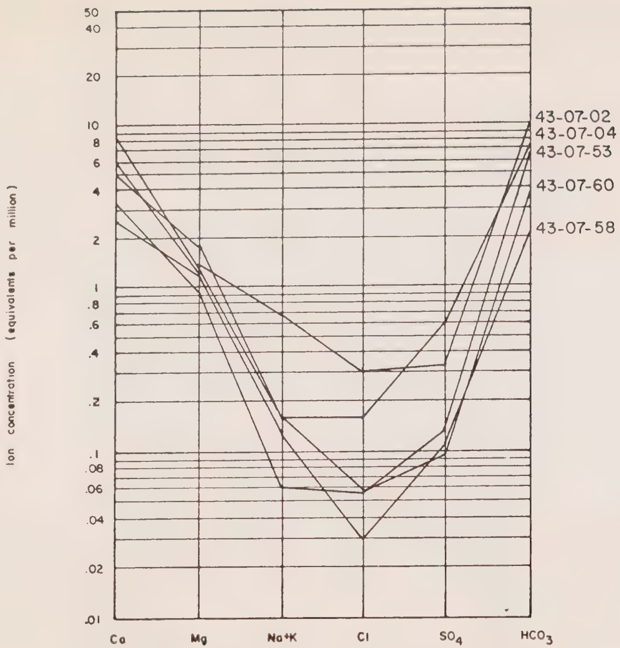


Calcium-bicarbonate type, Mg > Na, SO_4 > Cl

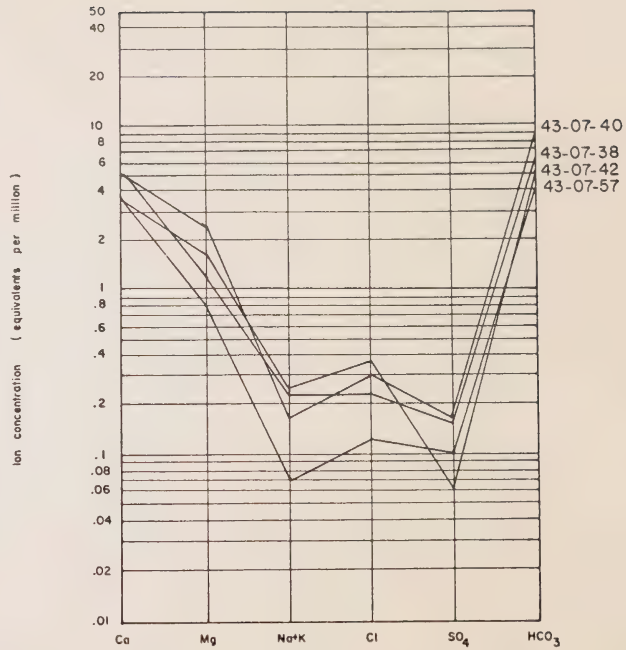


Calcium-bicarbonate type, Mg > Na, Cl > SO_4

Figure 58. Major-ion chemistry of ground water in overburden, Moose River basin.



Calcium-bicarbonate type, Mg > Na, SO_4 > Cl



Calcium-bicarbonate type, Mg > Na, Cl > SO_4

Figure 59. Major-ion chemistry of ground water in overburden, Albany River basin.

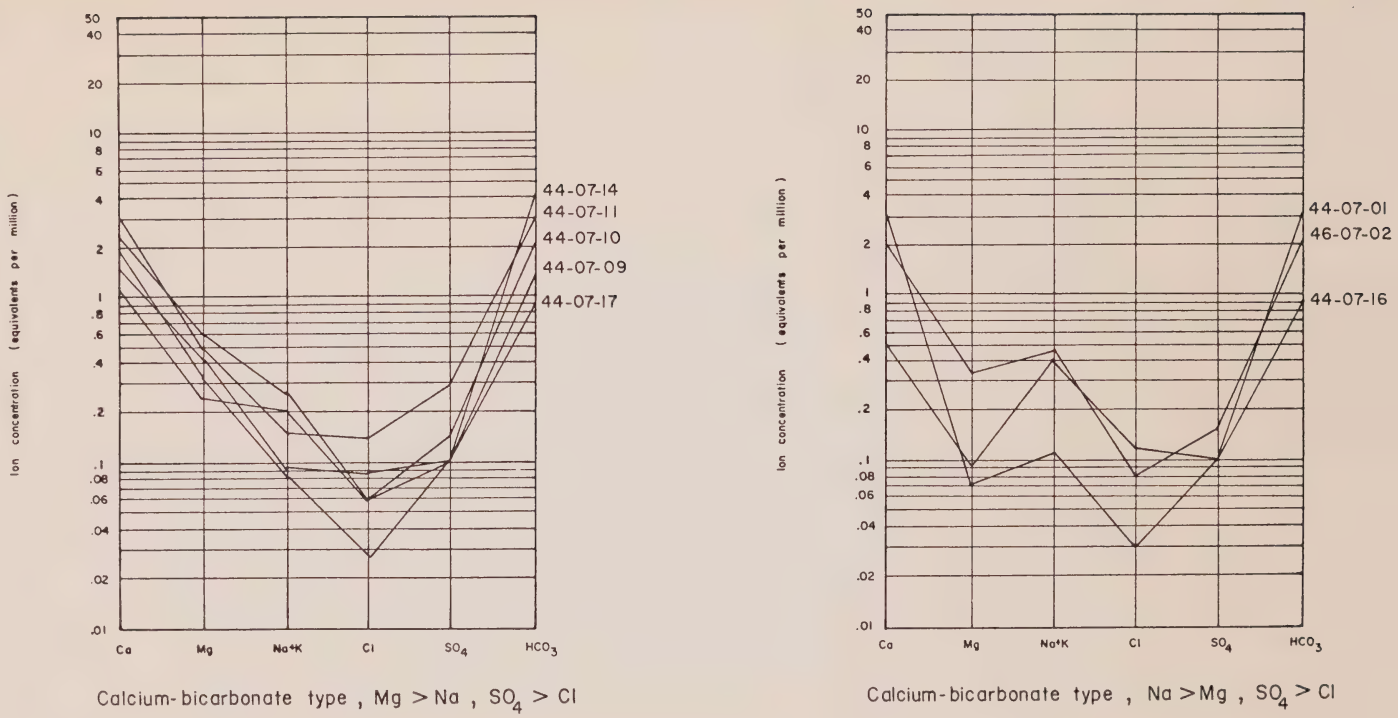
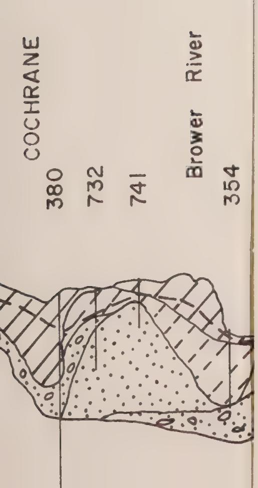


Figure 60. Major-ion chemistry of ground water in overburden , Attawapiskat and Winisk River basins.

NORTHERN
FIGURE 2–
HYDROGEOI



WATER RESOURCES REPORT 11b

Maps and Figure in Pocket:

Map 1 – Major Physiographic Regions
Map 2 – Bedrock Geology
Map 3 – Surficial Geology
Map 4 – Availability of Ground Water
Map 5 – Locations of Selected Water Wells
Map 6 – Hydrometric Stations and Sub - Basins
Map 7 – Ground - Water Sampling Locations 1966 - 1972
Figure 2 – Cross Sections, – Upper Moose River Basin

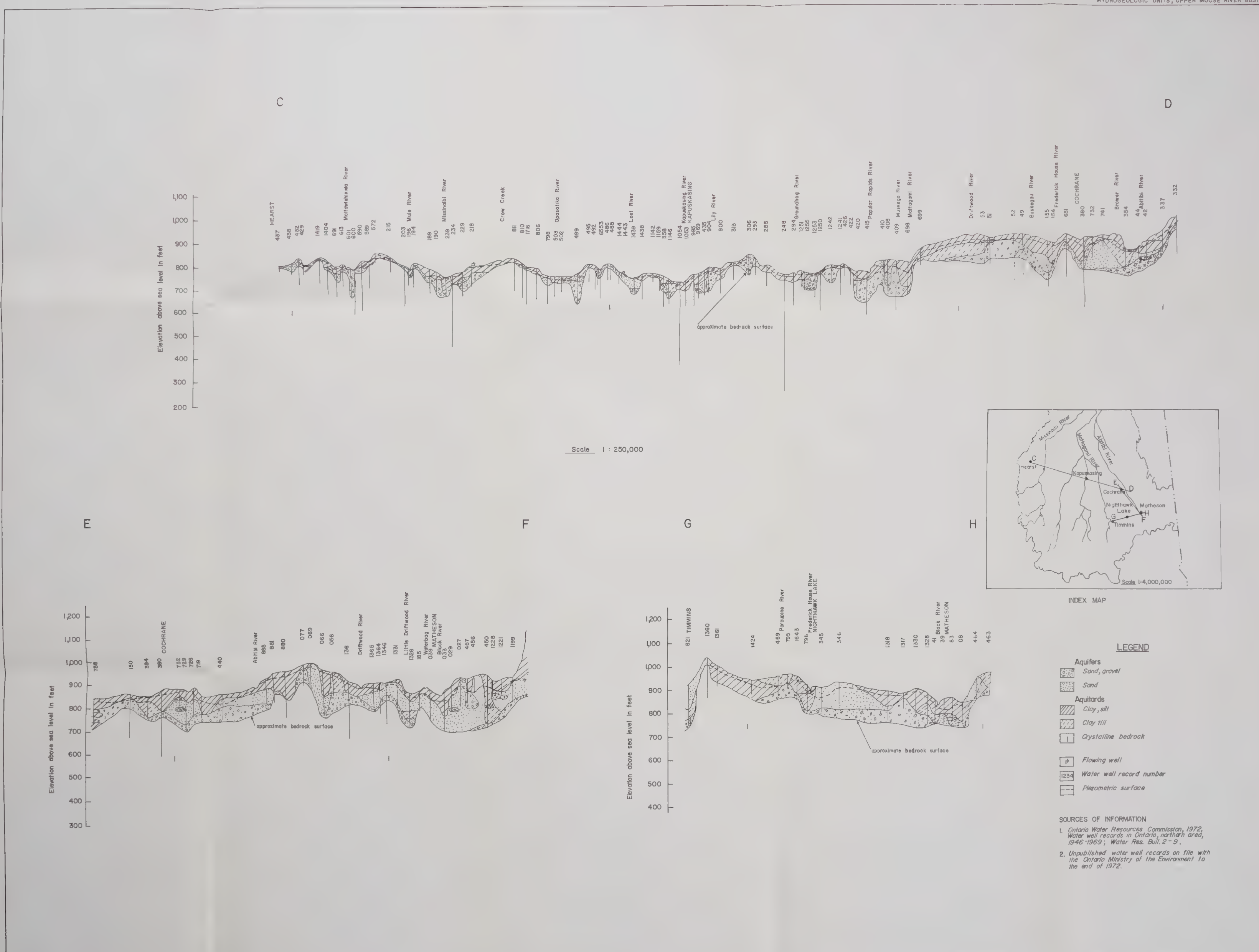


Figure 2. Cross sections showing overburden hydrogeologic units, upper Moose River basin.

Ontario

MINISTRY OF THE ENVIRONMENT
Water Resources Branch

NORTHERN ONTARIO WATER RESOURCES STUDIES

MAP 1

MAJOR PHYSIOGRAPHIC REGIONS

Scale 1:2,000,000

1 inch equals approximately 32 miles

Lambert Conformal Conic Projection
Standard Parallels 49°N and 54°N

LEGEND

A Hudson Bay Lowland Region

- Marine plain

B Precambrian Shield Region

- Till plain
- Lacustrine plain
- Upland area
- Major drainage divide
- Boundary of drainage basin
- Boundary of sub-basin subject to diversion

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Thurston P. C. and Carter, M. W., 1970, Operation Fort Hope, Ont. Dept. Mines and Northern Affairs, Misc. Paper 42

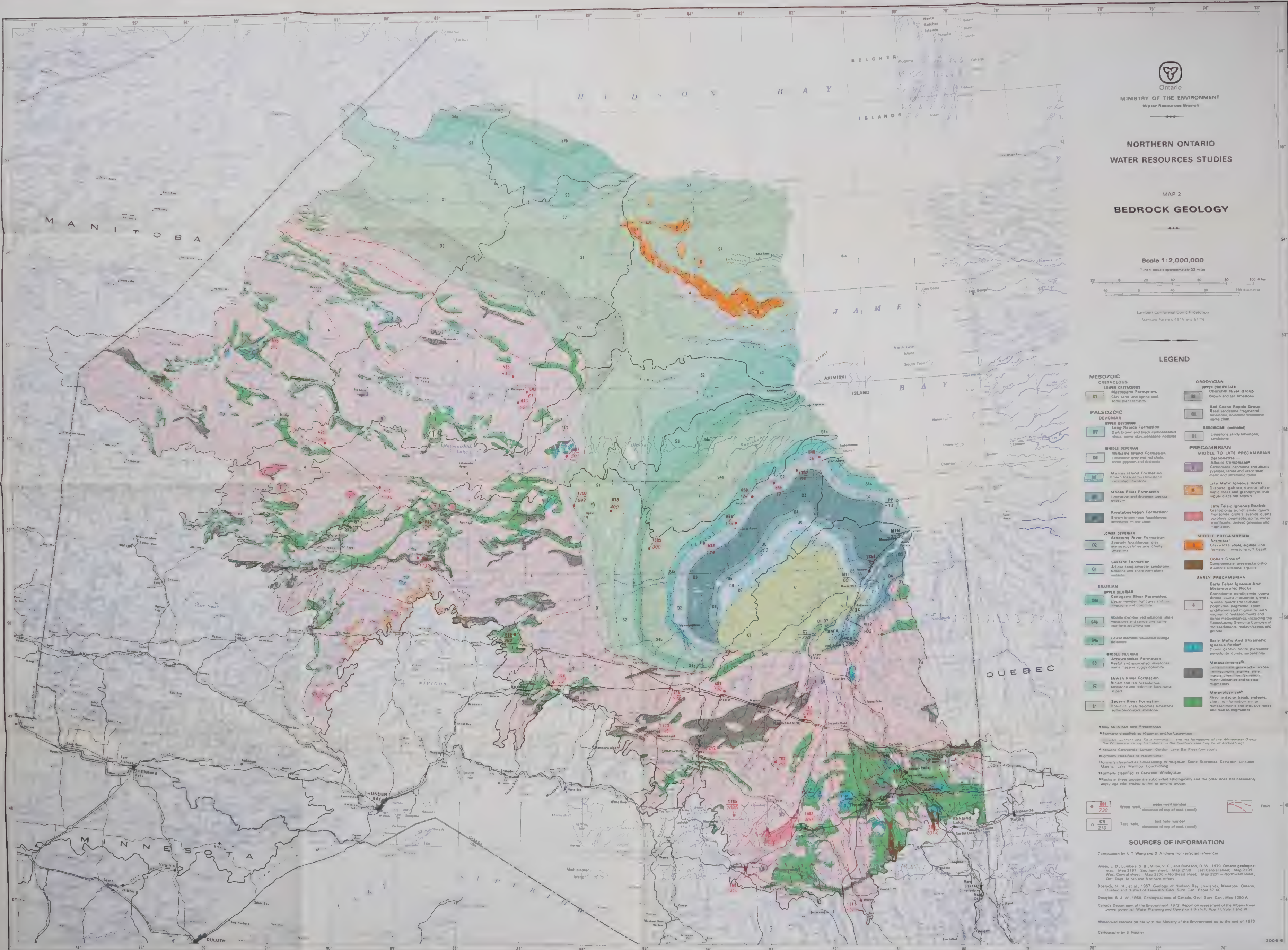
Zoltai, S. C., 1965, Surficial geology of Kenora Rainy River, Ont. Dept. Lands and Forests, Map S165

Zoltai, S. C., 1965, Surficial geology of Thunder Bay, Ont. Dept. Lands and Forests Map S265

Cartography by B. Fischer

2008-13

NORTHERN ONTARIO WATER RESOURCES STUDIES
MAP 2 - BEDROCK GEOLOGY




NORTHERN ONTARIO WATER RESOURCES STUDIES
MAP 3 SURFICIAL GEOLOGY
Ontario
MINISTRY OF THE ENVIRONMENT
Water Resources Branch
NORTHERN ONTARIO
WATER RESOURCES STUDIES
MAP 3
SURFICIAL GEOLOGY
Scale 1:2,000,000
Lambert Conformal Conic Projection
LEGEND
OVERBURDEN
QUATERNARY
Pleistocene and Recent
8 Aeolian deposits fine sand, silt
7 Marine deposits: clay and silt
6b Lacustrine deposits fine sand, sand
6a Lacustrine deposits varved or massive clay and silt
5 Outwash deposits fine sand, sand, gravel
4 Esker esker-kame complex sand, gravel, boulders
3 End moraine, interlobate moraine silt to sand till, sand, gravel, boulders
2b Ground moraine clay till
2a Ground moraine: silt to sand till
BEDROCK
1 Bedrock (undifferentiated)
Prominent strandlines
SOURCES OF INFORMATION
Compilation by K. T. Wang and D. Andrijiw from selected references and field data gathered by Ministry staff
Boissoneau, A. N., 1965. Surficial geology of Algoma-Cochrane. Ont. Dept. Lands and Forests. Map S365
Boissoneau, A. N. 1966. Surficial geology of Algoma Sudbury Timiskaming and Nipissing. Ont. Dept. Lands and Forests, Map S465
Bostock, H. H., et al., 1967. Geology of the Hudson Bay Lowlands, Manitoba, Ontario, Quebec and District of Keewatin. Geol. Surv. Can. Paper 67 60
Prest, V. K., 1963. Surficial geology of Red Lake Landsdowne House area, Ontario. Geol. Surv. Can. Paper 63 6
Prest, V. K., Grant, D. R. and Rampton V. N., 1967. Glacial map of Canada. Geol. Surv. Can. Map 1253 A
Zoltai, S. C., 1965. Surficial geology of Kenora Rainy River. Ont. Dept. Lands and Forests. Map S165
Zoltai, S. C., 1965, Surficial geology of Thunder Bay; Dept. Lands and Forests, Map S265
Cartography by B. Fischer
2006-7
HUDSON BAY
BELCHER ISLANDS
JAMES BAY
AKIMISKI ISLAND
MANITOBA
QUEBEC
MINNESOTA
LAKE SUPERIOR
THUNDER BAY
DULUTH
Kapuskasing
Cochrane
Timmins
Kirkland Lake
Noranda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NORTHERN ONTARIO
WATER RESOURCES STUDIES
MAP 4
AVAILABILITY
OF GROUND WATER
Scale 1: 2,000,000
1 inch equals approximately 32 miles
20 0 20 40 60 80 100 Miles
40 0 40 80 120 Kilometres
Lambert Conformal Conic Projection
Standard Parallels 49° N and 54° N
LEGEND
PROBABLE WELL YIELD
Low up to 5 gallons per minute
Low to moderate up to 25 gallons per minute
Moderate up to 200 gallons per minute
High more than 200 gallons per minute
Variable in varved silt and clay plains, average of 5 gallons per minute; in sand ridges, average of 25 gallons per minute; in sand plains, average of 200 gallons per minute
Note The probable yields indicated represent the quantity of water that can be expected from individual wells on a short-term basis and are estimated from geologic and hydrologic information contained in water well records, field notes and related references. The quality of water is generally satisfactory in most areas except in the lowlands where saline waters are commonly present, especially along the coast
AQUIFER LITHOLOGY
OVERBURDEN
Fine to medium sand related primarily to lacustrine deposits some sands may be of marine origin
Sand and gravel related primarily to outwash deposits in plains and to those bordering esker kame complexes end and interlobate moraines
Sand and gravel in eskers
Sand till related primarily to end and interlobate moraines
BEDROCK
Limestone
Limestone, dolomite
Carbonaceous shale
Siltstone sandstone
Sandstone, limestone
Crystalline bedrock
SOURCES OF INFORMATION
Interpretation by K. T. Wang
Bennett, G. and Riley, R. A., 1969, Operation Lingman Lake, Ont. Dept. Mines, Misc. Paper
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Boissoneau, A. N., 1965, Surficial geology of Algoma Cochrane, Ont. Dept. Lands and Forests, Map S365
Boissoneau, A. N., 1965, Surficial geology of Algoma, Sudbury, Timiskaming and Nipissing, Ont. Dept. Lands and Forests, Map S465
Bostock, H. H. et al., 1967, Geology of Hudson Bay Lowlands, Manitoba, Ontario, Quebec and District of Keewatin, Geol. Surv. Can., Paper 67-60
Canada Department of the Environment, 1972, Report on assessment of Albany River power potential, Water Planning and Operations Branch, App. II, Vols. I and VI
Prest, V. K., 1963, Surficial geology of Red Lake-Lansdowne House area, Ontario, Geol. Surv. Can., Paper 63-6
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Zoltai, S. C., 1965, Surficial geology of Kenora Rainy River, Ont. Dept. Lands and Forests, Map S165
Zoltai, S. C., 1965, Surficial geology of Thunder Bay, Ont. Dept. Lands and Forests, Map S265
Water well records on file with the Ontario Ministry of the Environment up to the end of 1973
Field notes on hydrogeology by G. Hamilton, K. T. Wang and R. Wilkins
Cartography by B. Fischer
2006-8
HUDSON BAY
BELCHER ISLANDS
JAMES BAY
AKIMISKI ISLAND
MANITOBA
QUEBEC
MINNESOTA
LAKE SUPERIOR
LAKE NIPIGON
THUNDER BAY
DULUTH
Kapuskasing


Ontario
MINISTRY OF THE ENVIRONMENT
Water Resources Branch
NORTHERN ONTARIO
WATER RESOURCES STUDIES
MAP 5
LOCATIONS OF
SELECTED WATER WELLS
Scale 1 : 2,000,000
1 inch equals approximately 32 miles
20 0 20 40 60 80 100 Miles
40 0 40 80 120 Kilometres
Lambert Conformal Conic Projection
Standard Parallels 49°N and 54°N
LEGEND
Test hole in overburden
Test hole in bedrock
Test hole in bedrock, flowing
Domestic well in overburden
Domestic well in bedrock
Municipal well in overburden
Municipal well in bedrock
Observation well in overburden
Observation well in bedrock
Domestic well in overburden, flowing
Domestic well in bedrock, flowing
Water-well number
This map shows the locations of wells as of December, 1972, for which water-well records have been filed with the Ontario Ministry of the Environment
Cartography by B. Fischer
H U D S O N B A Y
J A M E S B A Y
BELCHER ISLANDS
AKIMISKI ISLAND
M A N I T O B A
M I N N E S O T A
QUEBEC
DISTRICT OF KENORA
DISTRICT OF THUNDER BAY
DISTRICT OF COCHRANE
DISTRICT OF ALGOMA
DISTRICT OF SUDBURY
DISTRICT OF TIMISKAMING
L A K E S U P E R I O R
LAKE NIPIGON
THUNDER BAY
DULUTH
INSET MAP A
INSET MAP B
INSET MAP C
INSET MAP D
INSET MAP A - NAKINA AREA
Scale 1:100,000
INSET MAP B
PICKLE LAKE AREA
Scale 1:100,000
INSET MAP C - HEARST-KAPUSKASING AREA
Scale 1:1,000,000
INSET MAP D - COCHRANE-TIMMINS AREA
Scale 1:1,000,000
2006-12

MINISTRY OF THE ENVIRONMENT
Water Resources Branch

NORTHERN ONTARIO WATER RESOURCES STUDIES

MAP 6

HYDROMETRIC STATIONS AND SUB-BASINS

Scale 1: 2,000,000

1 inch equals approximately 32 miles

Lambert Conformal Conic Projection
Standard Parallels 49°N and 54°N

LEGEND

▲	04DA001	Streamflow gauging station, recording gauge
★	PICKLE LAKE	Meteorologic station
⊙	*44-05-004*	Ground-water observation well, manual measurement
⊙	*43-05-002R*	Ground-water observation well, recording gauge
⊙	*43-05-017(2)*	Ground-water observation well, (two piezometers), manual measurement

42 MOOSE RIVER BASIN

1 Black River
2 Upper Abitibi River
3 Upper Mattagami River
4 Middle Mattagami River
5 Groundhog River
6 Kapuskasing River
7 Upper Missinaibi River
8 Lower Abitibi River
9 Lower Mattagami River
10 Lower Missinaibi River
11 North French River
12 Lower Moose River
13 Kwataboahegan River

43 ALBANY RIVER BASIN

1 Kabinakagami River
2 Shekak River
3 Nagagami River
4 Long Lake
5 Kapikotongwa River
6 Ogoki River
7 Lake St. Joseph
8 Cat Lake
9 Upper Albany River
10 Middle Albany River
11 Kenogami River
12 Lower Albany River

44 ATTAWAPISKAT RIVER BASIN

1 Otoskwin River
2 Pineimuta River
3 Upper Attawapiskat River
4 Middle Attawapiskat River
5 Lower Attawapiskat River

46 WINISK RIVER BASIN

1 Pipestone River
2 Upper Winisk River
3 Upper Asheweig River
4 Lower Asheweig River
5 Middle Winisk River
6 Shamattawa River
7 Lower Winisk River

47 SEVERN RIVER BASIN

1 Windigo River
2 Deer Lake
3 Upper Severn River
4 Upper Sachigo River
5 Big Trout Lake
6 Middle Severn River
7 Lower Sachigo River
8 Lower Severn River

SOURCES OF INFORMATION

Compilation by K. T. Wang

Ontario Ministry of the Environment, 1973, Hydrometric Stations 1972, water resources survey, northern Ontario, map 2006-10, Water Quantity Management Branch

Cartography by B. Fischer

Ontario

MINISTRY OF THE ENVIRONMENT

Water Resources Branch

NORTHERN ONTARIO WATER RESOURCES STUDIES

MAP 7

GROUND-WATER SAMPLING LOCATIONS 1966-1972

Scale 1: 2,000,000

1 inch equals approximately 32 miles

Lambert Conformal Conic Projection

Standard Parallels 49°N and 54°N

LEGEND

42-07-46 — Sample number
0.65 — Total iron concentration (ppm)
192 — Total hardness as $CaCO_3$ (ppm)
2 — Chloride concentration (ppm)
350 — Total dissolved solids concentration (ppm)

46 Drainage basin number

- Bored well in overburden
- Drilled well in overburden
- Drilled well in bedrock
- Flowing well in bedrock
- Spring
- Lignite pit

Note A: Complete analyses of water samples are published in Water Resources Bulletins 1-1 to 1-5, General Series. Since the sample numbers shown on this map do not appear in any of the Bulletins, cross-referencing of samples must be made through longitudes and latitudes; these are shown for samples in the Bulletins, and must be determined for samples on the map.

SOURCES OF INFORMATION

Compilation by K. T. Wang

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__________, 1970, Data for northern Ontario water resources studies 1968 to 1969; Water Resour. Bull. 1-2, Gen. Series

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Ministry of the Environment, 1973, Data for northern Ontario water resources studies 1971; Water Resour. Bull. 1-4, Gen. Series

__________, 1975, Data for northern Ontario water resources studies 1972-1973; Water Resour. Bull. 1-5, Gen. Series

Cartography by B. Fischer

2006-11

Lambert Conformal Conic Projection